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Wexler et al.

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(54) **TANK FILLING SYSTEM AND METHOD**

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F17C 5/06 (2006.01)
F17C 13/02 (2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ***F17C 5/06*** (2013.01); ***F17C 5/007*** (2013.01); ***F17C 13/026*** (2013.01); ***F17C 13/04*** (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC F17C 5/06; F17C 5/007; F17C 13/026; F17C 13/04; F17C 2201/0138;

(Continued)

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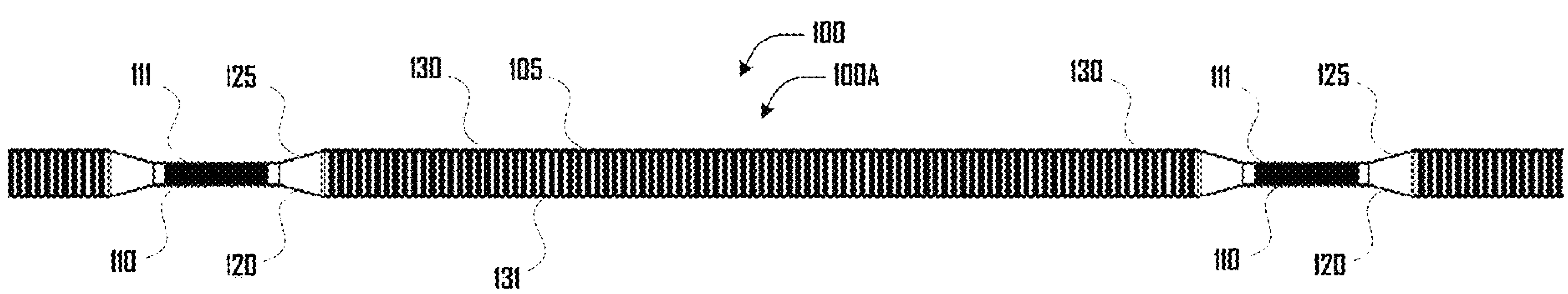
(57) **ABSTRACT**

A Venturi filling system having a first filling coupler configured to be coupled to a first set of fittings disposed at a first tank end of a tank; a second filling coupler configured to be coupled to a second set of fittings disposed at a second tank end of the tank; and a Venturi assembly that includes: a Venturi mixing chamber, the Venturi mixing chamber communicating with the first filling coupler; a Venturi nozzle configured to introduce a first flow of fluid from a fluid source to the Venturi mixing chamber of the Venturi assembly; and an suction inlet communicating with the second filling coupler and coupled with the Venturi chamber and configured to receive a second flow of fluid originates from the second filling coupler such that the second flow of fluid flows into the Venturi chamber and mixes with the first fluid flow within the Venturi mixing chamber.

14 Claims, 17 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 62/620,935, filed on Jan. 23, 2018, provisional application No. 62/479,699, filed on Mar. 31, 2017.

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F17C 13/04 (2006.01)
F17C 5/00 (2006.01)

(52) **U.S. Cl.**
CPC *F17C 2201/0138* (2013.01); *F17C 2201/0195* (2013.01); *F17C 2203/0604* (2013.01); *F17C 2205/0111* (2013.01); *F17C 2205/037* (2013.01); *F17C 2205/0332* (2013.01); *F17C 2205/0338* (2013.01); *F17C 2205/0341* (2013.01); *F17C 2209/21* (2013.01); *F17C 2209/2109* (2013.01); *F17C 2221/011* (2013.01); *F17C 2221/012* (2013.01); *F17C 2221/018* (2013.01); *F17C 2221/033* (2013.01); *F17C 2221/035* (2013.01); *F17C 2223/0123* (2013.01); *F17C 2223/0161* (2013.01); *F17C 2223/035* (2013.01); *F17C 2223/036* (2013.01); *F17C 2225/0123* (2013.01); *F17C 2250/034* (2013.01); *F17C 2250/043* (2013.01); *F17C 2250/0439* (2013.01); *F17C 2250/075* (2013.01); *F17C 2270/0139* (2013.01)

(58) **Field of Classification Search**
CPC F17C 2201/0195; F17C 2203/0604; F17C 2205/0111; F17C 2205/0332; F17C 2205/0338; F17C 2205/0341; F17C 2205/037; F17C 2209/21; F17C 2209/2109; F17C 2221/011; F17C 2221/012; F17C 2221/018; F17C 2221/033; F17C 2221/035; F17C 2223/0123; F17C 2223/0161; F17C 2223/035; F17C 2223/036; F17C 2225/0123; F17C 2250/034; F17C 2250/043; F17C 2250/075; F17C 2270/0139
See application file for complete search history.

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U.S. Appl. No. 15/940,793, filed Mar. 29, 2018.
U.S. Appl. No. 15/940,862, filed Mar. 29, 2018.

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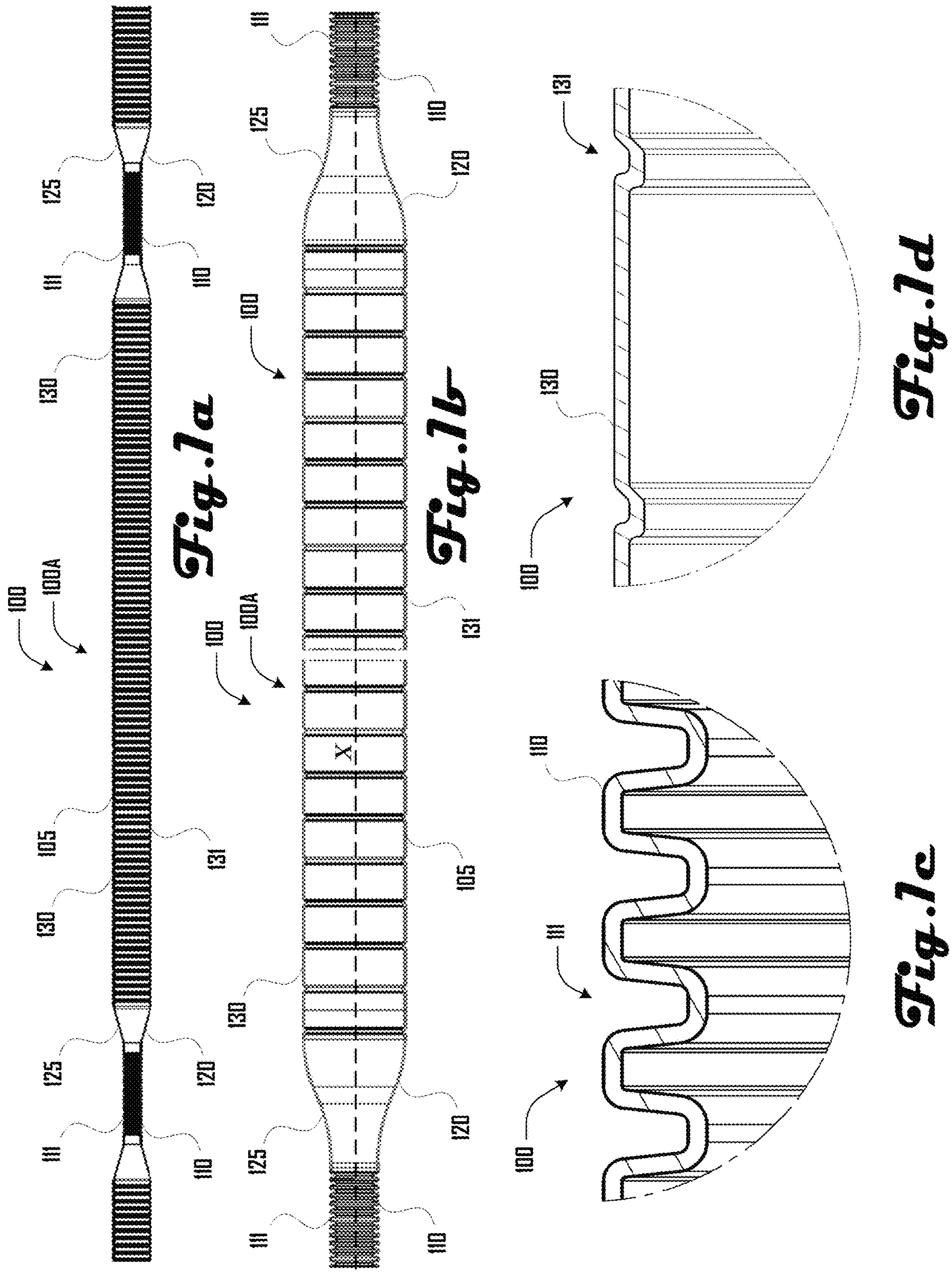

Fig.1a

Fig.1b

Fig.1c

Fig.1d

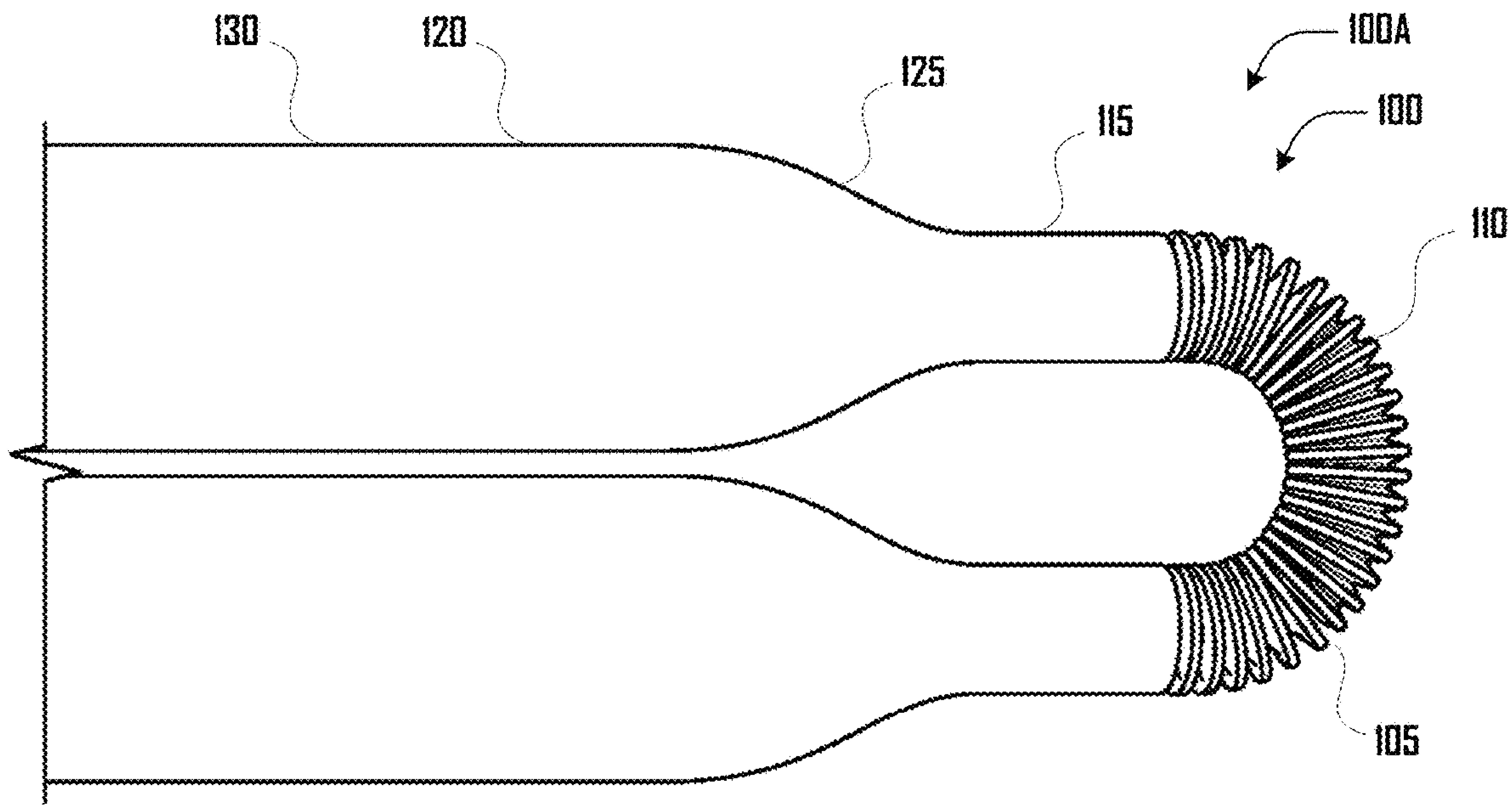

Fig. 2a

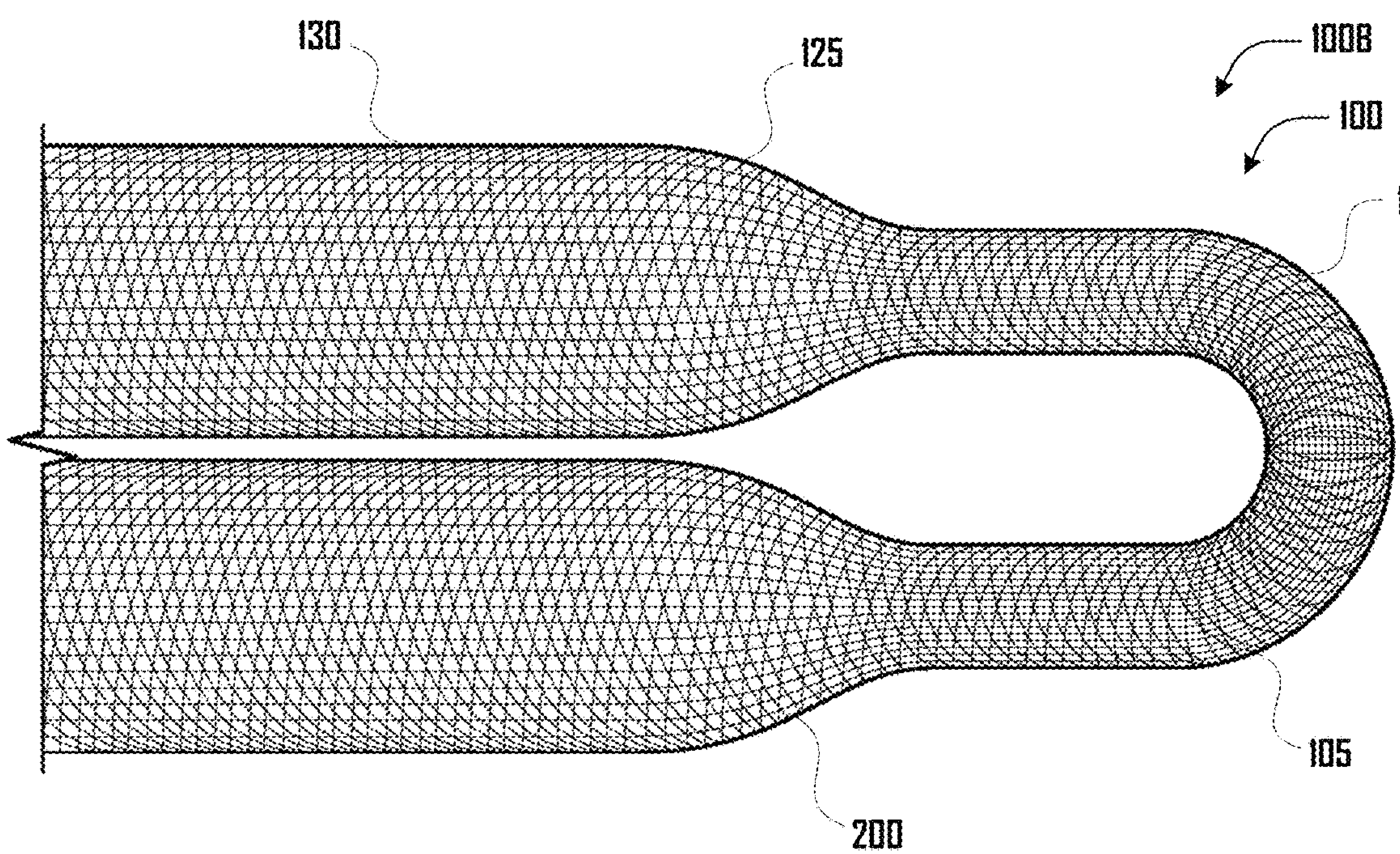

Fig. 2b

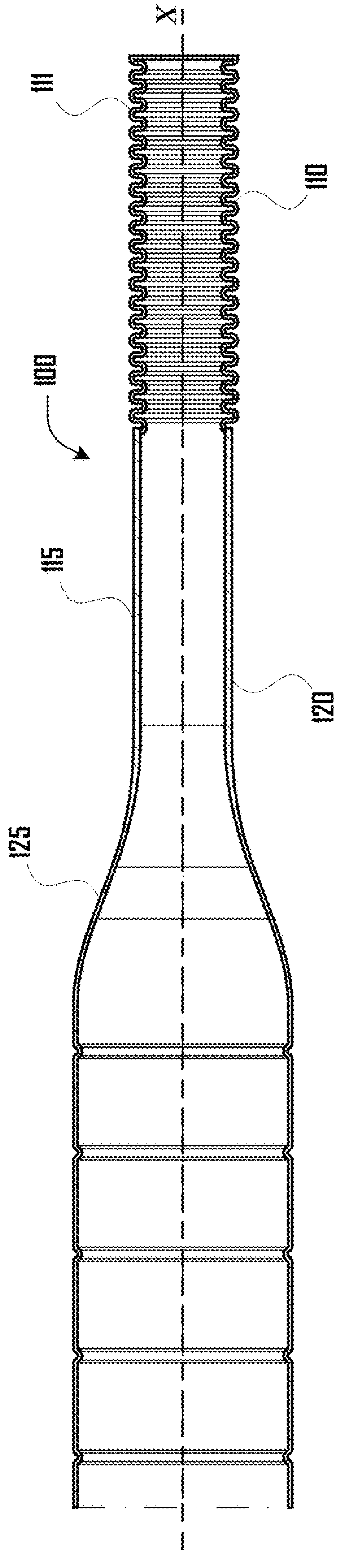

Fig. 3

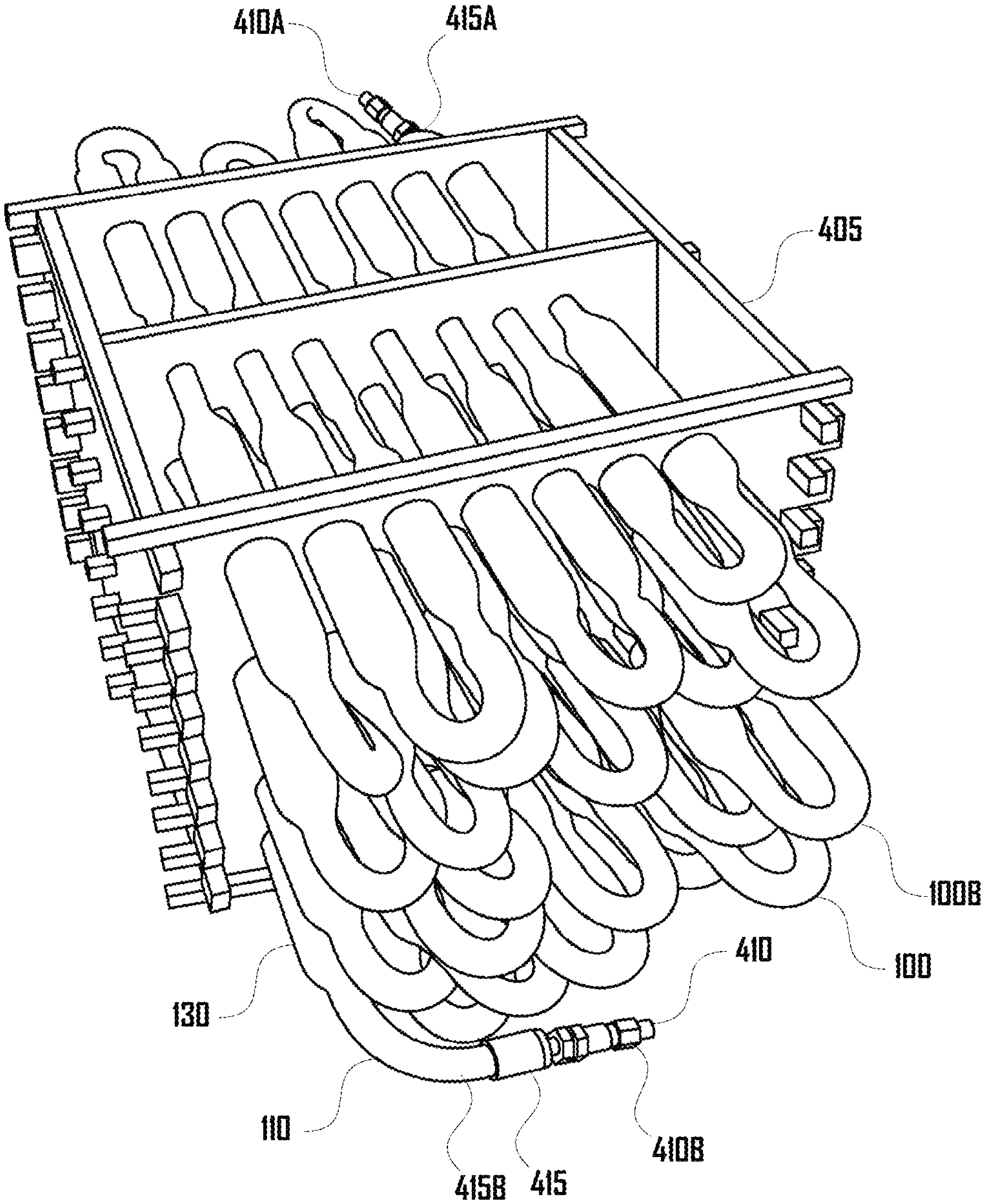

Fig. 4

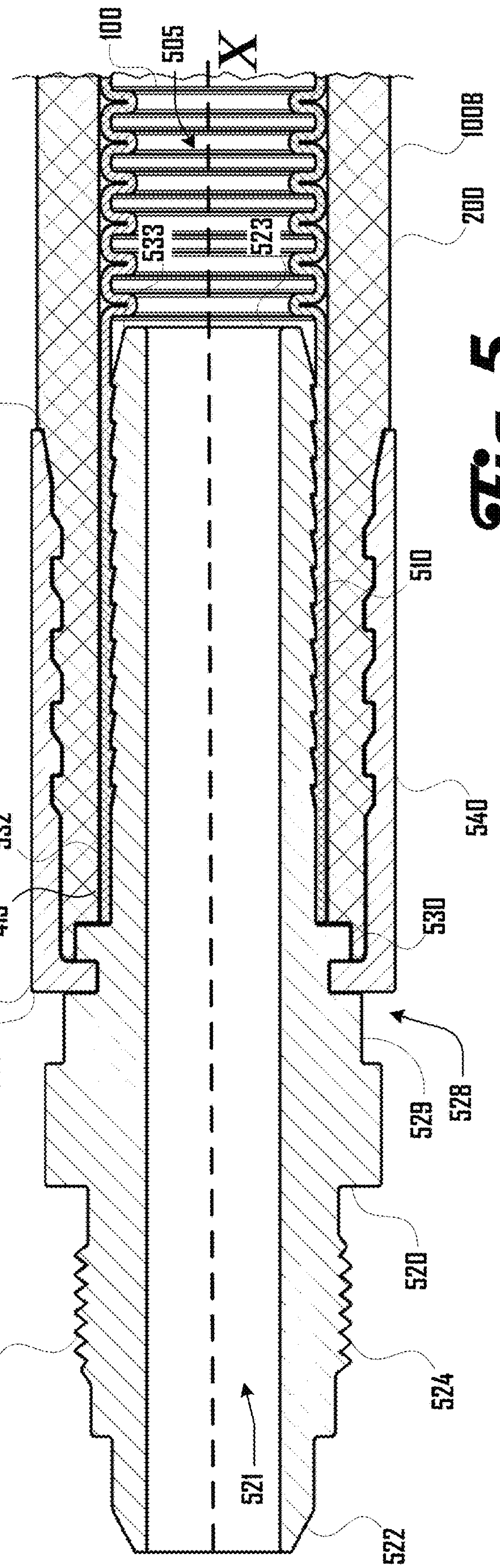
100
505
X
100B
200
533
523
542
510
540
410
532
415
530
541
544
529
528
520
525
524
521
522

Fig. 5

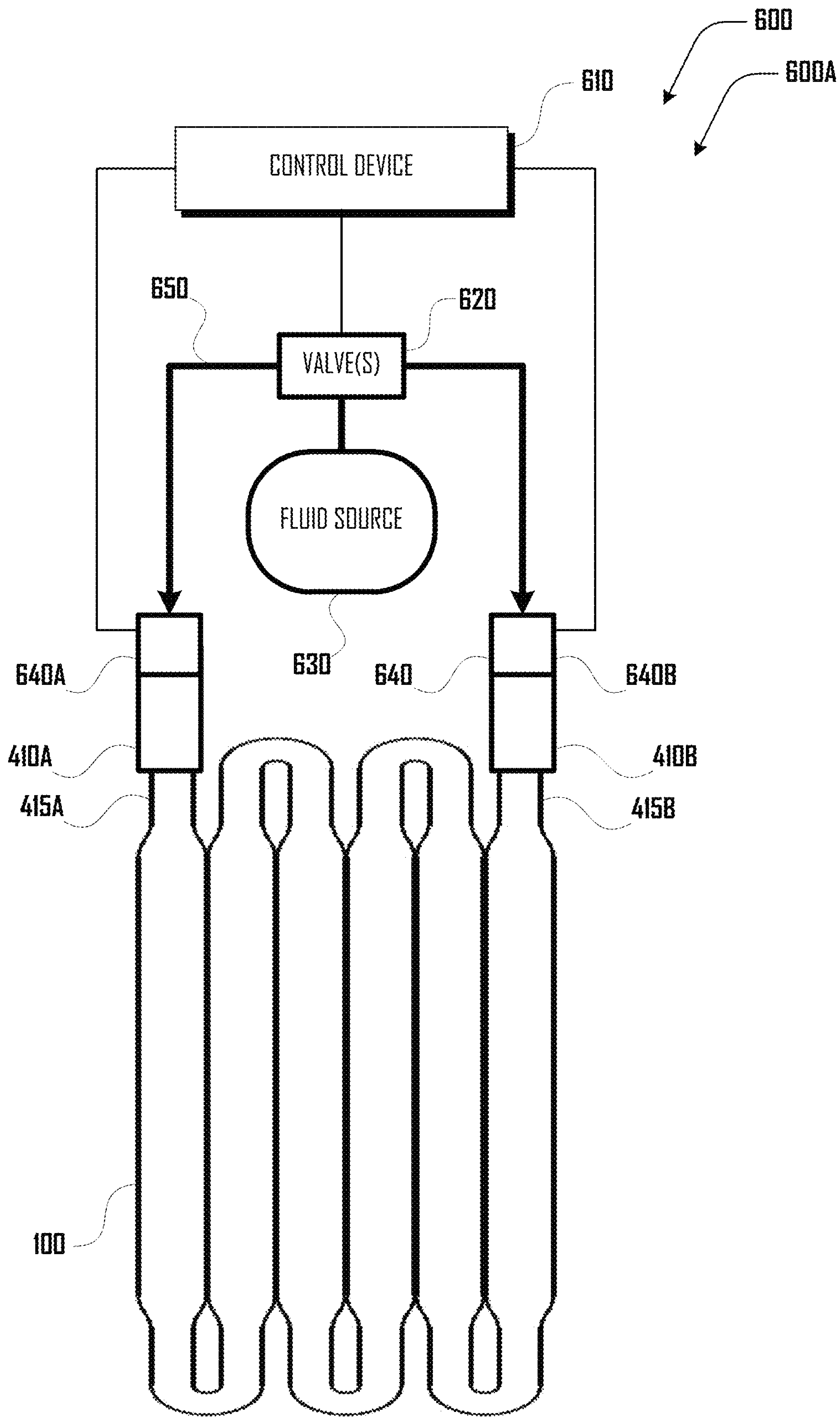
600
600A
610
CONTROL DEVICE
650
620
VALVE(S)
FLUID SOURCE
630
640A
640
640B
410A
410B
415A
415B
100

Fig. 6

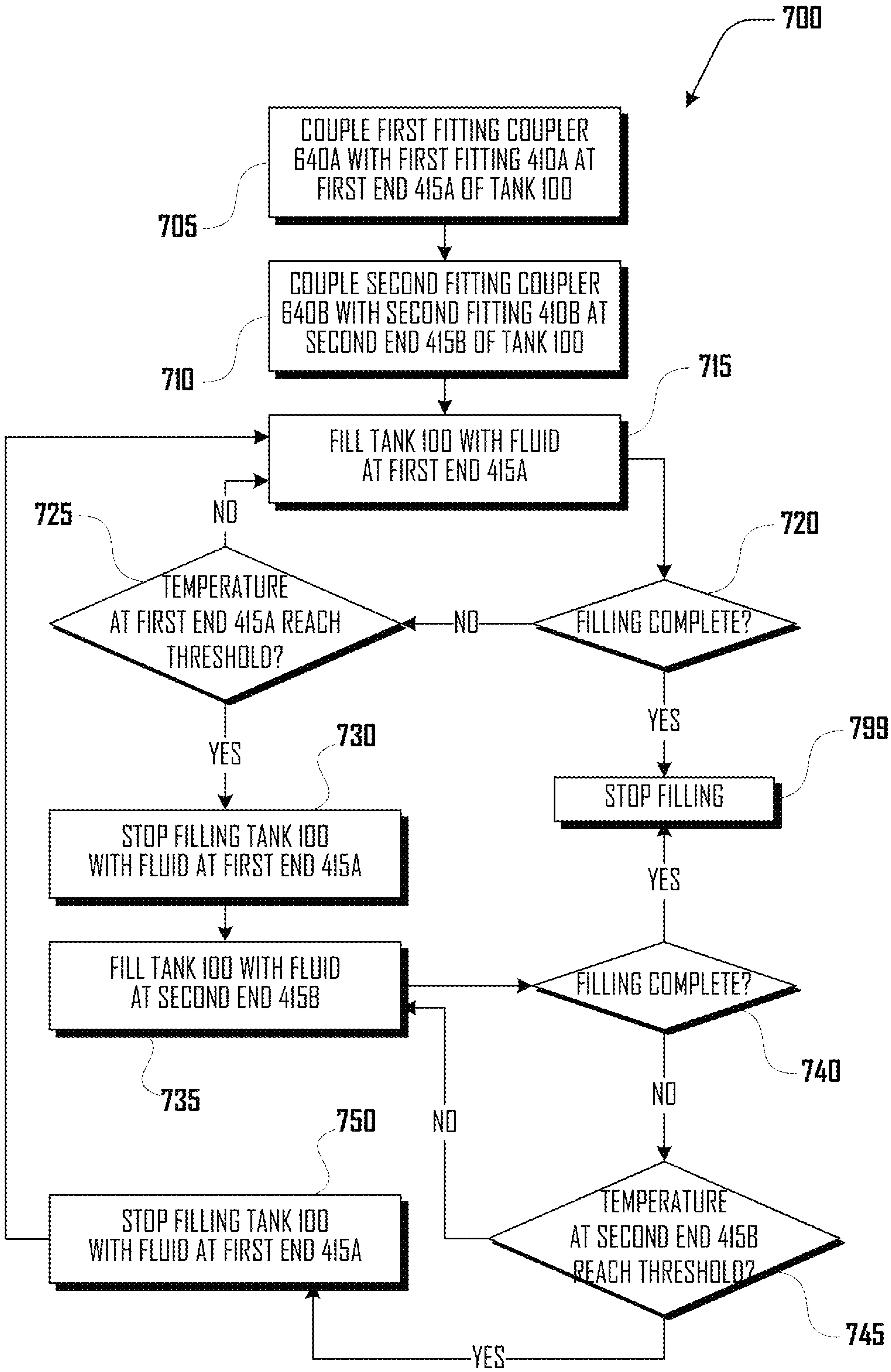
700
COUPLE FIRST FITTING COUPLER 640A WITH FIRST FITTING 410A AT FIRST END 415A OF TANK 100
705
COUPLE SECOND FITTING COUPLER 640B WITH SECOND FITTING 410B AT SECOND END 415B OF TANK 100
710
FILL TANK 100 WITH FLUID AT FIRST END 415A
715
FILLING COMPLETE?
720
NO
TEMPERATURE AT FIRST END 415A REACH THRESHOLD?
725
NO
YES
STOP FILLING
799
YES
STOP FILLING TANK 100 WITH FLUID AT FIRST END 415A
730
FILL TANK 100 WITH FLUID AT SECOND END 415B
735
YES
FILLING COMPLETE?
740
NO
TEMPERATURE AT SECOND END 415B REACH THRESHOLD?
745
NO
STOP FILLING TANK 100 WITH FLUID AT FIRST END 415A
750
YES

Fig. 7

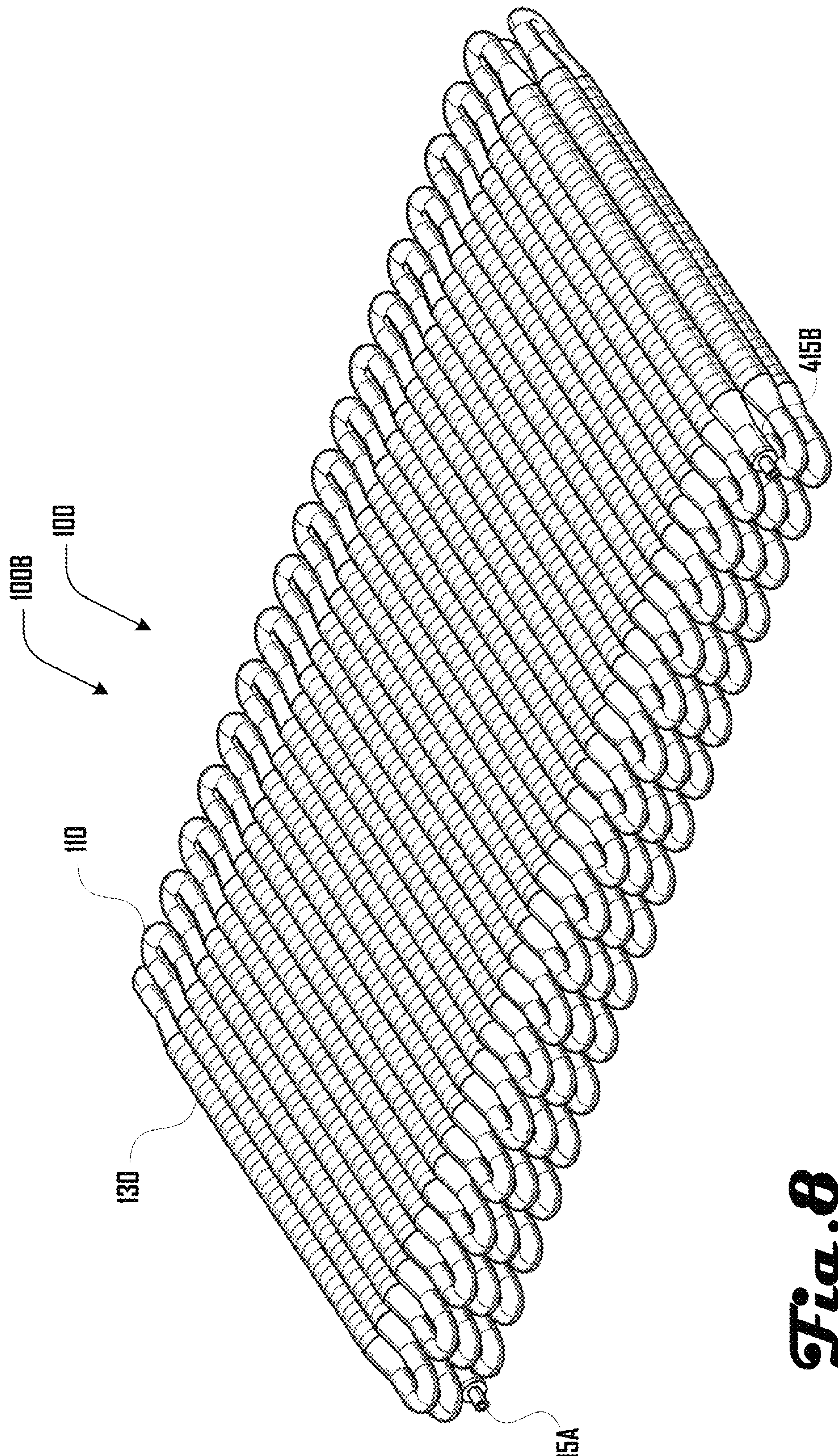

Fig. 8

„Conventional“ 5 kg 70 MPa Type IV HDPE tank

Parameter	Value	Unit
Total length	800	mm
External diameter	553	mm
Wall thickness liner	5	mm
Wall thickness composite	35.334	mm
Liner density	945	kg/m³
Liner thermal conductivity	0.5	W/(m*K)
Liner specific heat capacity	2100	J/(kg*K)
Composite density	1494	kg/m³
Composite thermal conductivity	0.5	W/(m*K)
Composite specific heat capacity	1120	J/(kg*K)

Fig. 9a

Case #	Precool Temp.	Heat transfer to ambient
1	-33°C	5 W/m²K
2	0°C	5 W/m²K
3	none	5 W/m²K
4	0°C	0 W/m²K

Fig. 9b

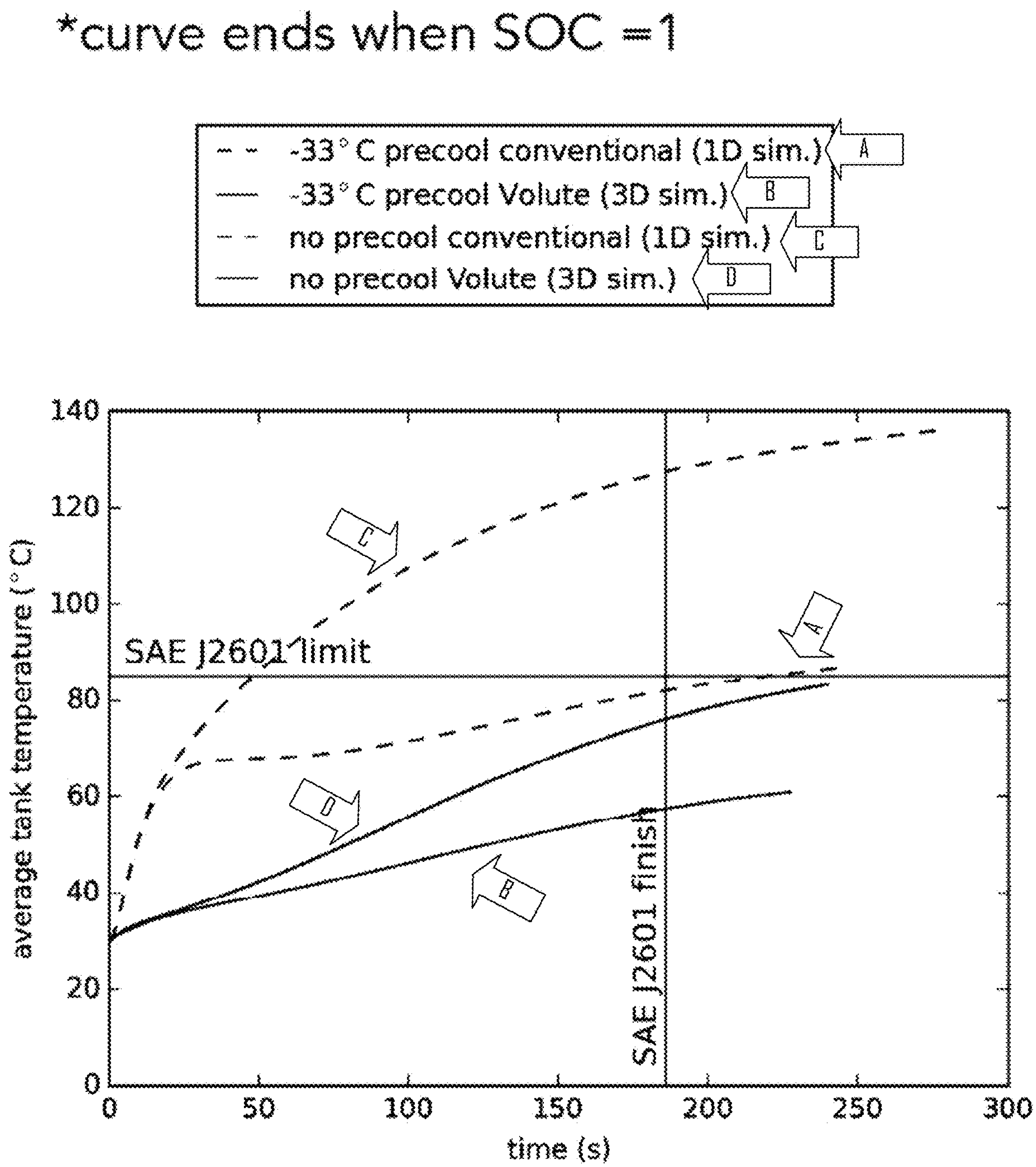
*curve ends when SOC =1
-33° C precool conventional (1D sim.)
A
-33° C precool Volute (3D sim.)
B
no precool conventional (1D sim.)
C
no precool Volute (3D sim.)
D
average tank temperature (° C)
SAE J2601 limit
SAE J2601 finish
time (s)
0
50
100
150
200
250
300
20
40
60
80
100
120
140

Fig. 10

Tank	Precool	Time	P_{avg}	T_{avg}
Conventional	-33°C	248 s	88 MPa	87°C
Conventional	none	279 s	100 MPa	136°C
Volute	-33°C	242 s	86 MPa	62°C
Volute	none	240 s	85 MPa	83°C

Fig. 11

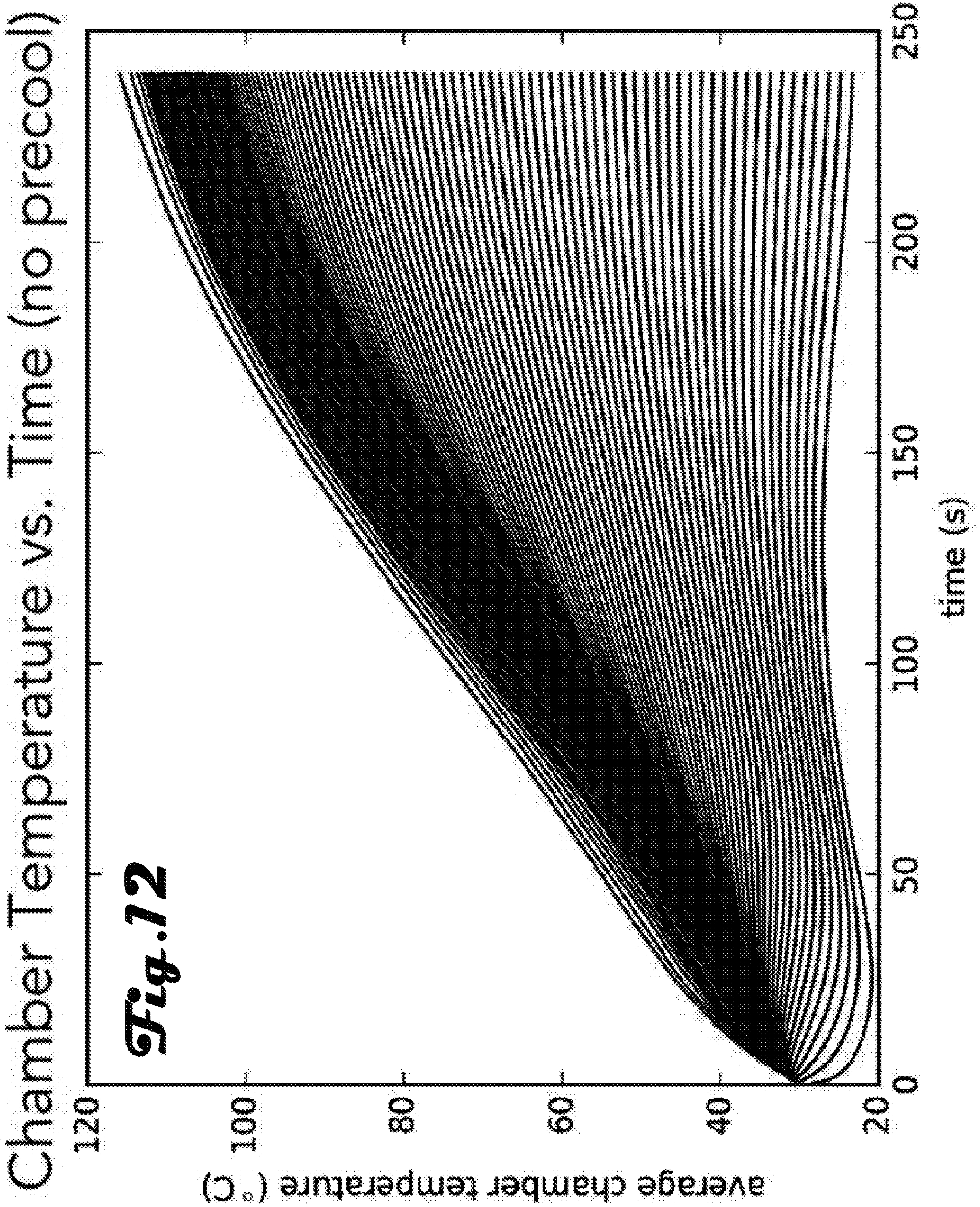
Chamber Temperature vs. Time (no precool)
average chamber temperature (°C)
120
100
80
60
40
20
time (s)
0
50
100
150
200
250

Fig. 12

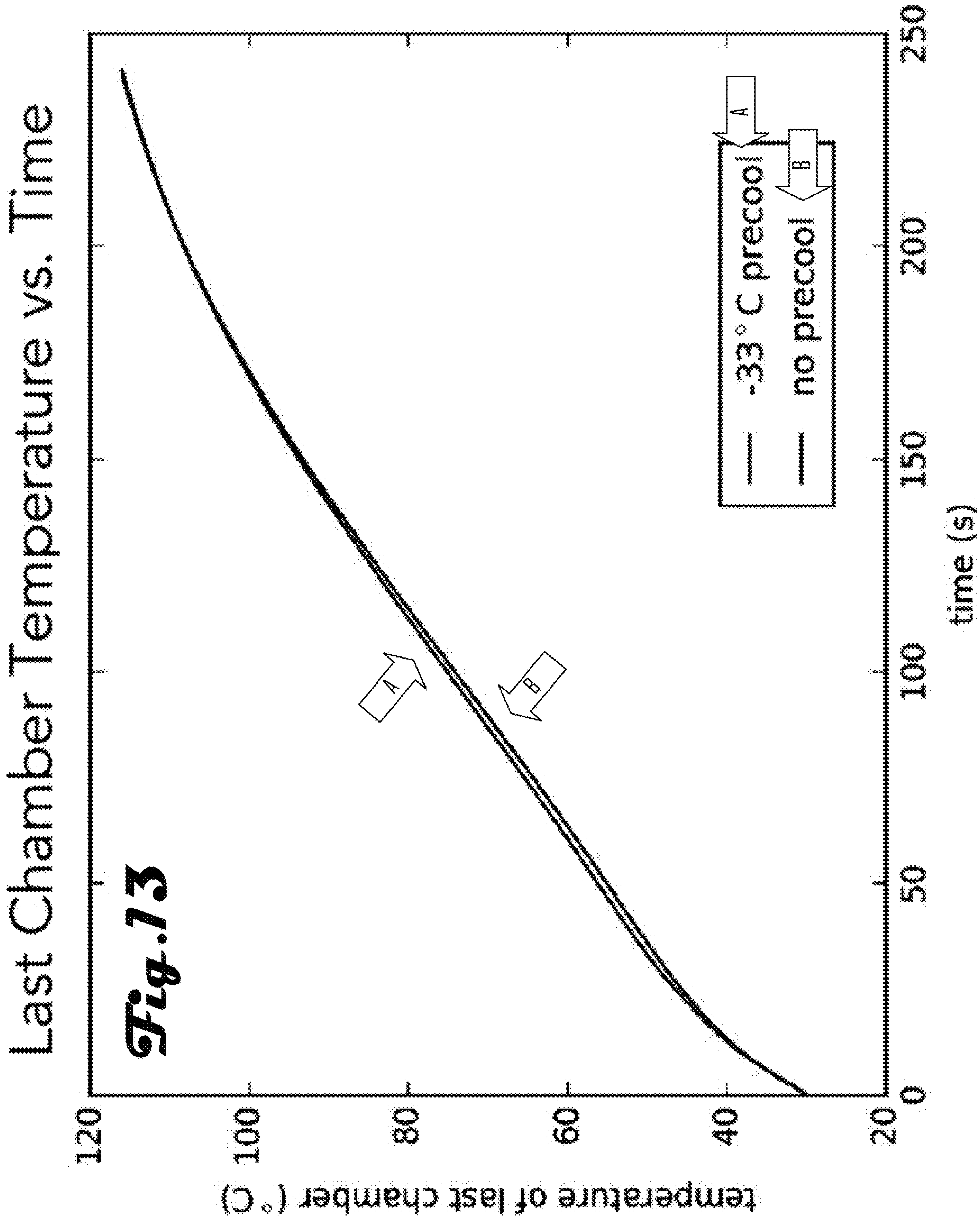
Last Chamber Temperature vs. Time
temperature of last chamber (° C)
120
100
80
60
40
20
0
50
100
150
200
250
time (s)
-33° C precool
no precool
A
B

Fig.13

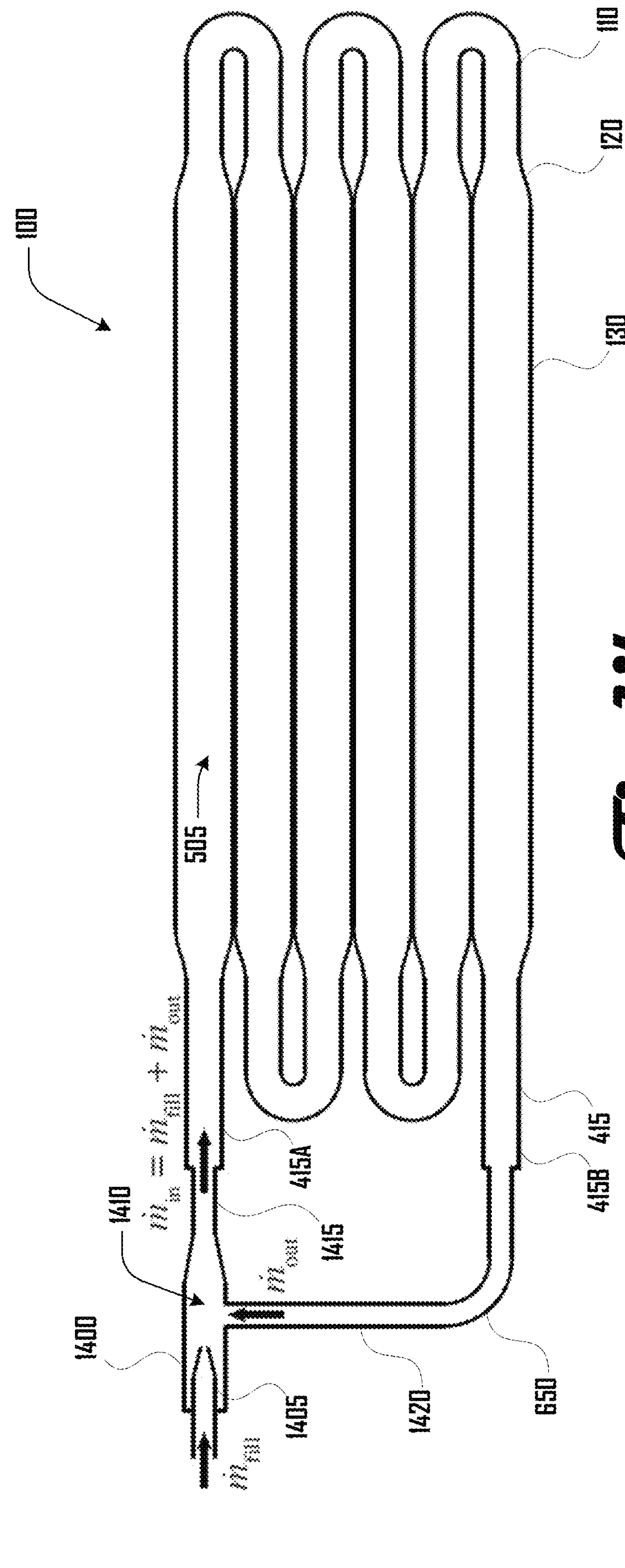
100
110
120
130
505
415
415A
415B
1415
1410
1400
1405
1420
650
$\dot{m}_{in} = \dot{m}_{fill} + \dot{m}_{out}$
$\dot{m}_{out}$
$\dot{m}_{fill}$

Fig. 14

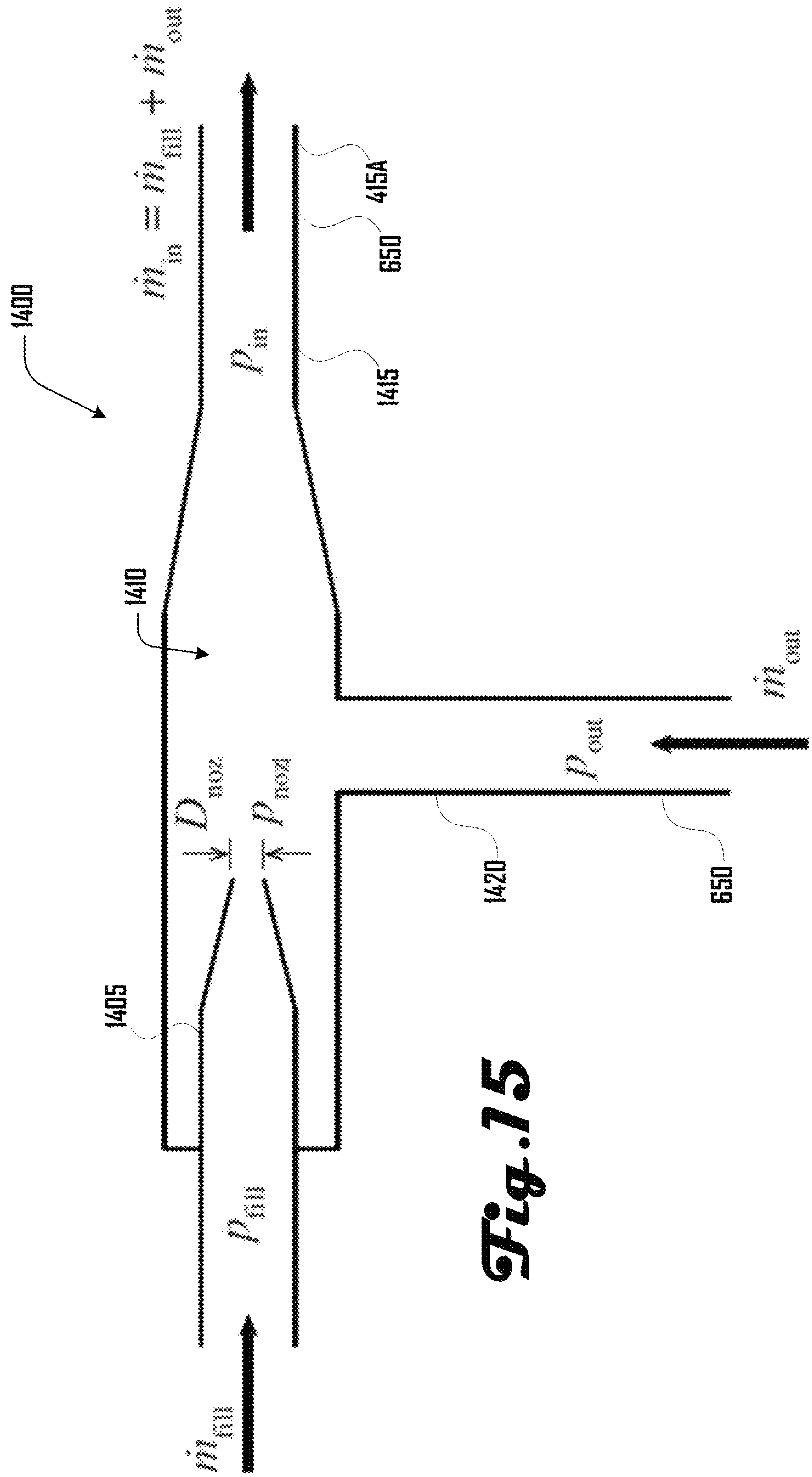
$\dot{m}_{in} = \dot{m}_{fill} + \dot{m}_{out}$
1400
415A
650
p_{in}
1415
1410
$\dot{m}_{out}$
p_{out}
D_{noz}
p_{noz}
1420
650
1405
p_{fill}
$\dot{m}_{fill}$

Fig.15

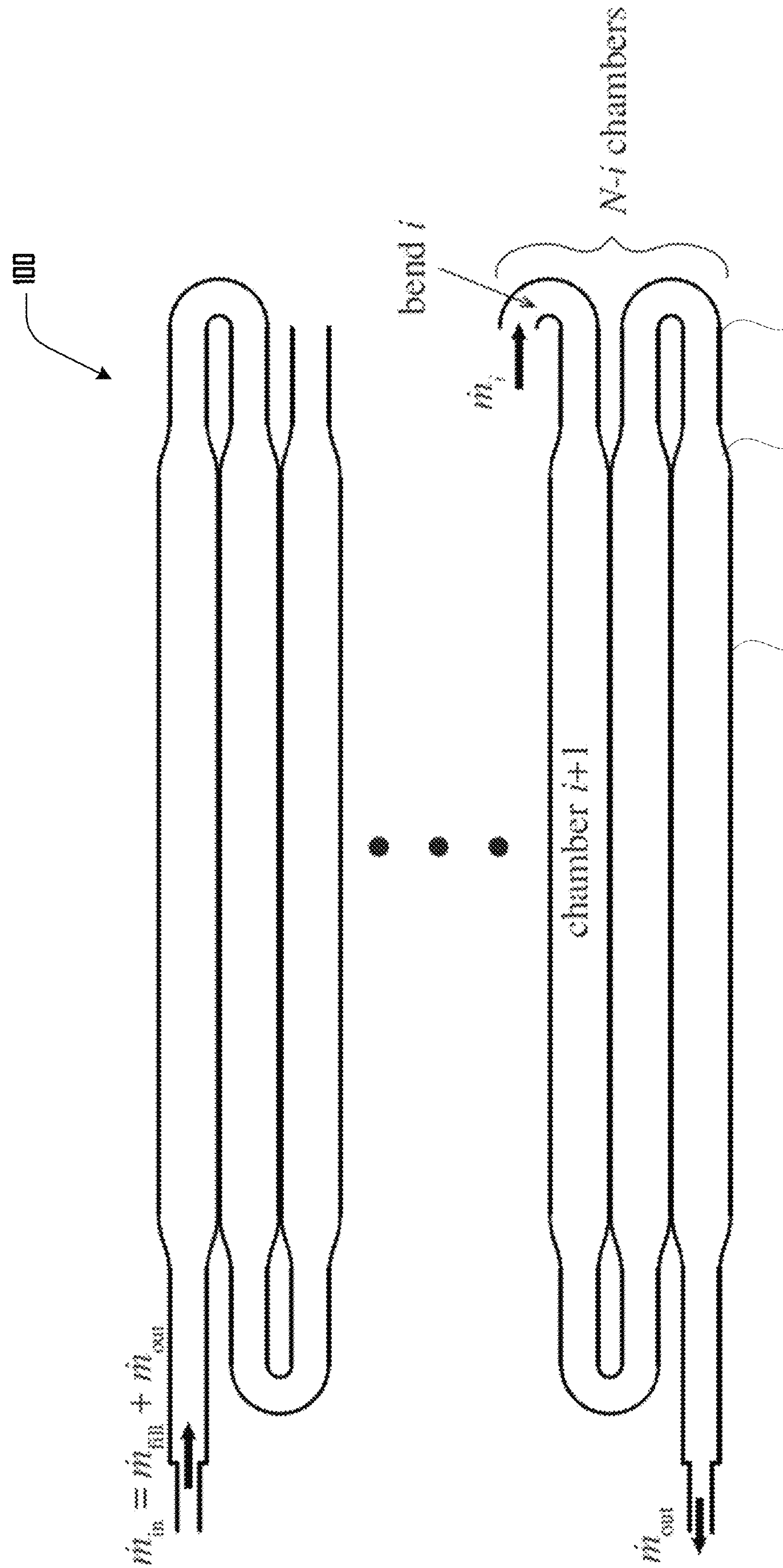

Fig. 16

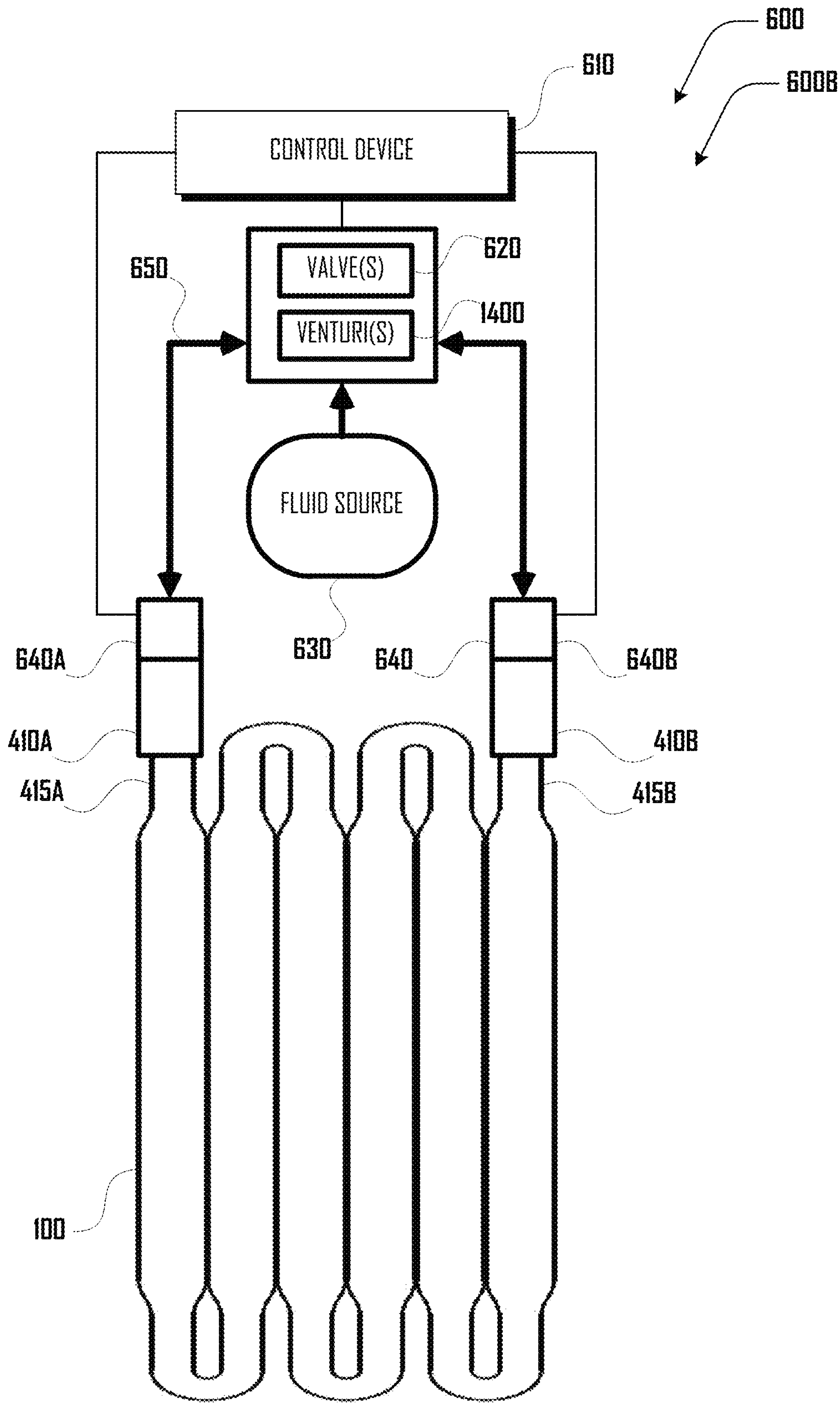
600
600B
610
CONTROL DEVICE
620
VALVE(S)
650
1400
VENTURI(S)
FLUID SOURCE
640A
630
640
640B
410A
410B
415A
415B
100

Fig. 17

TANK FILLING SYSTEM AND METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 15/940,862, filed Mar. 29, 2018, which is a non-provisional of and claims priority to U.S. Provisional applications entitled "FAST-FILL TANK SYSTEM AND METHOD" and "TANK FILLING SYSTEM AND METHOD" and respectively having application Nos. 62/479,699 and 62/620,935 respectively filed Mar. 31, 2017 and Jan. 23, 2018. These applications are hereby incorporated herein by reference in their entirety and for all purposes.

This application is related to U.S. application Ser. No. 13/887,201 filed May 3, 2013; U.S. application Ser. No. 14/172,831 filed Feb. 4, 2014; U.S. application Ser. No. 15/183,614 filed Jun. 15, 2016; U.S. application Ser. No. 14/624,370 filed Feb. 17, 2015; U.S. application Ser. No. 15/368,182 filed Dec. 2, 2016; U.S. application Ser. No. 15/792,090 filed Oct. 24, 2017; U.S. Application Ser. No. 62/479,598 filed Mar. 31, 2017; U.S. Application Ser. No. 62/479,699 filed Mar. 31, 2017. These applications are hereby incorporated herein by reference in their entirety and for all purposes.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1***a* and **1***b* illustrate side views of a bare liner comprising a body having connector portions, taper portions and tubing portions.

FIG. **1***c* illustrates a close-up side view of corrugations of connector portions of a bare liner.

FIG. **1***d* illustrates a close-up side view of corrugations of tubing portions of a bare liner.

FIG. **2***a* illustrates a side view of a bare liner bending via corrugations of the connector portions.

FIG. **2***b* illustrates a side view of the liner of FIG. **2***a* covered with braiding.

FIG. **3** illustrates a side view of a bare liner comprising a body having a connector portion with a cuff and corrugations, a taper portion and tubing portion.

FIG. **4** illustrates one embodiment of a tank that is folded and held in a stacking architecture defined by a plurality of transverse planks that engage with a plurality of lateral planks.

FIG. **5** illustrates a cutaway side view of a set of fittings coupled to an end of a tank.

FIG. **6** is a diagram of a tank filling system in accordance with an embodiment.

FIG. **7** is a block diagram of a method of filling a tank with fluid in accordance with one embodiment.

FIG. **8** illustrates an example tank having one hundred and twelve chambers in accordance with one embodiment.

FIG. **9***a* illustrates parameters of a conventional tank used in a simulation study performed for the tank shown in FIG. **8**.

FIG. **9***b* illustrates four cases used to perform a 3D and 1D simulation.

FIG. **10** is a plot of average tank temperature over time for the simulations.

FIG. **11** is a table of data obtained in the simulations.

FIG. **12** is a plot of average chamber temperature over time with no precool.

FIG. **13** is a plot of last chamber temperature over time.

FIG. **14** is a schematic showing a Venturi assembly connected to a 6-chamber tank, circulating gas flow during the filling of an example 6-chamber tank with fluid.

FIG. **15** is a schematic showing the Venturi assembly of FIG. **14** circulating the flow during the filling of a tank with fluid.

FIG. **16** is a schematic showing a tank having i+3 chambers.

FIG. **17** is a block diagram of a tank filling system in accordance with another embodiment.

It should be noted that the figures are not drawn to scale and that elements of similar structures or functions are generally represented by like reference numerals for illustrative purposes throughout the figures. It also should be noted that the figures are only intended to facilitate the description of the preferred embodiments. The figures do not illustrate every aspect of the described embodiments and do not limit the scope of the present disclosure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Turning to FIGS. **1***a*-*d*, a bare liner **100**A is shown as comprising a body **105** having connector portions **110**, taper portions **125** and tubing portions **130**. The connector portion **110** can be corrugated, which can allow the connector portion **110** to be flexible such that the liner **100** can be folded into a housing **300** as illustrated in FIGS. **3***a* and **3***b*. Non-corrugated portions **120** can be rigid in various embodiments.

In various embodiments, the connector portion **110** can have a diameter that is smaller than the tubing portions **130**, with the taper portion **125** providing a transition between the diameter of the connector portion **110** and the tubing portion **130**. However, further embodiments can comprise a liner **100** with portions having one or more suitable diameter, and in further embodiments, a liner **100** can have portions that are non-cylindrical, which can include various suitable shapes. The connector portion **110** can comprise connector corrugations **111**, which can allow the connector portion **110** to be flexible (e.g., as illustrated in FIGS. **2***a* and **2***b*) such that the liner **100** can be folded into a housing **300** as illustrated in FIGS. **3***a* and **3***b*.

Additionally, as illustrated in FIGS. **1***a*, **1***b*, **2***a* and **3** the connector portion **110** can comprise a cuff portion **115** defined by a non-corrugated portion **120** or rigid portion of the connector portion **110** between the corrugations **111** of the connector portion **110** and the taper portion **125**. In further embodiments, the cuff portion **115** can be various sizes as illustrated in FIGS. **1***a*, **1***b*, **2***a* and **3**. More specifically, FIGS. **1***a* and **1***b* illustrate a cuff portion **115** being smaller compared to the cuff portion **115** illustrated in FIGS. **2***a* and **3**. In some embodiments, the cuff portion **115** can have a length that is less than, equal to, or greater than the length of the taper portion **125**. In some embodiments, the taper portion **125** can have a length that is less than, equal to, or greater than the length of the cuff portion **115** or twice the length of the cuff portion **115**.

Similarly, in some embodiments, the tubing portions **130** can comprise corrugations **131**. However, in further embodiments, the corrugations **131** can be absent from the tubing portions (e.g., as illustrated in FIG. **2***a*). Non-corrugated portions **120** can be rigid in various embodiments.

In one embodiment, the liner **100** can be generated via extrusion molding systems or the like, which can comprise rotating dies that are configured to rotate in concert such that corresponding dies mate about an extruded tube generated by an extruder. Corresponding mated dies can thereby define one or more of the connector portion **110**, taper portion **125** and/or the tubing portion **130**.

In various embodiments, a vacuum can pull the material of an extruded tube to conform to negative contours defined by the mated die. In some embodiments, positive pressure can be introduced within the tube to conform to negative contours defined by the mated die. In various embodiments, such a manufacturing process can be beneficial because liners **100** can be made seamlessly, with no welds, and using a single material.

In some embodiments, liners **100** having varying lengths of the connector portion **110**, taper portion **125** and/or the tubing portion **130** can be made by selectively choosing the order of dies such that desired portions are made longer or shorter. For example, in some embodiments, a liner **100** can be produced that fits into an irregular or non-rectangular cavity, which can require a liner **100** to have tubing portions **130** of variable lengths.

In some embodiments, a liner **100** can be made by forming various pieces of the liner **100** and then coupling the pieces together. For example, connector portion **110** can be manufactured separately from the taper portion **125** and/or the tubing portion **130**, and/or the cuff portion **115**. Such separate portions can be subsequently coupled together to form the liner **100**.

A liner **100** can comprise various suitable materials including plastic, metal, or the like. In some preferred embodiments, a liner **100** can comprise Ultramid PA6, Rilsamid PA12, Lupolen HDPE, or the like.

Accordingly, the embodiments of a liner **100** shown and described herein should not be construed to be limiting on the wide variety of liners **100** that are within the scope and spirit of the present invention. For example, liners **100** as described in U.S. Provisional Patent Application No. 62/175,914, which is incorporated herein by reference, illustrate some further example embodiments of liners **100**.

In some embodiments, a liner **100** can be a naked liner **100**A as illustrated in FIGS. **1***a-d*, and **2***a*. However, as illustrated in FIG. **2***b*, in some embodiments a liner **100** can be a covered or over-braided liner **100**B, which can include a braiding **200** or other suitable covering. An over-braided liner **110**B can be desirable because the braiding **200** can increase the strength of the liner and thereby increase the duty pressure under which the liner **100** may safely operate. Additionally, braiding **200** can be disposed in a plurality of layers in various embodiments. For example, in one preferred embodiment, the braid **200** can comprise six layers of 48 carrier carbon braid **200**.

As discussed in detail herein, the material(s), shape, size, configuration and other variables related to a braid **200** can be chosen to increase the strength provided by the braiding **200**, increase the flexibility of the braiding **200**, increase the strength to weight ratio of the braiding, and the like. In various preferred embodiments, braiding **200** can be configured to completely cover a liner **100**. In other words, one or more layers of braiding **200** can be configured to cover the liner **100** such that the liner is not visible through the braid **200** once applied to the liner **100** and such that gaps between the braid are not present such that the liner **100** is visible through the braid **200**.

In various embodiments, the tank **100** can be folded into a three-dimensional structure. For example, FIG. **4** illustrates one embodiment where an over-braided liner **100**B is folded and held in a stacking architecture **405**. The tank **100** can also include fittings **410** disposed at ends **415** of the tank **100**. More specifically, a first fitting **410**A can be coupled at a first end **415**A of the tank **100** and a second fitting **410**B can be coupled at a second end **415**B of the fitting. Although FIG. **4** illustrates fittings **410** coupled to the connector portion **110** of the tank **100**, in further embodiments, fittings can be coupled at any suitable portion of the tank **100**, including the cuff portions **115**, taper portions **125** and/or tubing portions **130**. Such fittings **410** can include crimp fittings, bolt fittings, or any other suitable type of fitting. Examples of fittings in accordance with some embodiments are shown and described in U.S. patent application Ser. No. 15/792,090 entitled FITTINGS FOR COMPRESSED GAS STORAGE VESSELS, filed Oct. 24, 2017, which as discussed above is incorporated herein by reference in its entirety for all purposes.

In various embodiments, such fittings **410** can be configured to interface with a tank valve and have a hollow center bore that is not only large enough to allow the passage of a fluid but also large enough to allow the pass-through of valve instrumentation, or the like. For example, in various embodiments, such tank valves can be instrumented to detect tank conditions within the tank **100**, including temperature, pressure, or the like, as described in more detail herein.

In some embodiments, a tank **100** can comprise smooth cuffs **115** at one or both ends **415** of the tank **100** for fitting attachment (e.g., as illustrated in FIGS. **2***a* and **3**, but with the corrugated portion **105** removed). In some examples, connector portions **110** can comprise cuff sections **115** and corrugation sections **105** to allow for a smooth attachment surface for crimp fittings **410**. However, in further embodiments, with modification to tooling mold blocks or the like, it is possible to incorporate cuff sections **115** to the end sections **415** of the tank **100**, leaving internal connector portions **110** completely corrugated. Such cuff sections **115** at ends **415** of the tank **100** can be various suitable diameters, which can be the same size as, larger than, or smaller than internal connector portions **110**, and such connector portions **110** can be completely or partially corrugated. In other words, some embodiments can include repeating tank geometries for internal portions of the tank **100** between the ends **415**, with a different tank geometry on the ends **415** of the tank **100**. Non-periodic tank geometries can be generated in various suitable ways including a liner forming machine with swappable mold blocks as discussed herein, or the like.

Turning to FIG. **5**, fittings **410** can be configured to couple with ends **415** of a liner **100**. In some embodiments, fittings **410** can be configured to couple with an over-braided liner **100**B that includes a liner **100**, which is surrounded by one or more layer of braiding **200** as illustrated in FIG. **5**. For example, fittings **410** can comprise a stem **520** and a ferrule **540**, which are configured to couple with an end **415** of a liner **100** that is surrounded by one or more layer of braiding **200** as described in detail herein.

Fittings **410** can be made of various suitable materials including metal, plastic, or the like. In some embodiments, fittings **410** can be configured to be in contact with compressed hydrogen and can be configured to be resistant to hydrogen embrittlement or weakening of the fittings **410** and fracturing resulting from hydrogen diffusion into the fittings **410**. For example, the fittings **410** can comprise a material and/or surface coating that is resistant to hydrogen induced fracturing.

The stem **520** can define a bore **521** that extends through the stem **520** along an axis X between a first and second end **522**, **523**. In some embodiments having a larger diameter bore **521** can be desirable to increase the flow rate through the bore **521**, which can be desirable for faster filling.

Additionally, a larger diameter bore **521** can be desirable for allowing sensors to be inserted into the bore **521** and into the interior cavity **505** defined by the liner **100**.

The stem **520** can comprise a head **524** that includes threads **525**, which can be configured to couple with various systems such that suitable fluids can be introduced to and/or removed from an interior cavity **505** defined by the liner **100** as described in more detail herein. For example, where such a fluid comprises hydrogen, the head **524** can be directly or indirectly coupled with a hydrogen filling station to fill the interior cavity **505** defined by the liner **100** with hydrogen and can be directly or indirectly coupled with a vehicle engine to provide hydrogen fuel to the vehicle engine from hydrogen stored within the interior cavity **505** defined by the liner **100**.

The head **524** can also connect to various other suitable components including a valve, pressure regulator, thermally activated pressure relief device, temperature sensor, pressure sensor, or the like. While various example embodiments discussed herein relate to a male conical shape of a head **524** that can be configured to seal against a corresponding female cone, further coupling or mating structures of various configurations can be implemented in further embodiments. For example, in one embodiment, the head **524** can comprise an O-ring face-seal, an O-ring bore-seal, or the like.

Additionally, various components can be configured to extend into a fitting **410** or into the cavity **506** defined by the over-braided liner **100**B. For example such components can include at least a portion of a gas injector, a gas receiver (e.g., including a filter and an excess flow valve), a temperature sensor, a pressure sensor, a bleed valve, a temperature pressure relief device (TPRD), and the like. In some embodiments such components can be inserted into and reside within the bore **521** of the stem **520** and/or within the cavity **505** defined by the liner. In various embodiments, it can be desirable to have a large diameter bore **521** to accommodate such components.

The head **524** can extend to a coupling architecture **528** defined by a first and second rim **529**, **530** disposed on opposite sides of and defining a coupling groove **531**. A coupling body **532** can extend from the coupling architecture **528** and terminate at the tip **533** disposed at the second end **523** of the stem **520**.

The ferrule **540** can comprise a cylindrical body having a first and second end **541**, **542** with a lip **544** defining a coupling orifice at the first end **541**. The ferrule **540** can further define a cavity that extends between the first and second end **541**, **542** and opens to the coupling orifice at the first end **541** and an opening at the second end **542**.

In various embodiments, the stem **520** and ferrule **540** can couple about an end **415** of an over-braided liner **100**B in various suitable ways such that a fluid-tight seal is generated by the resulting fitting **410**. Such a coupling can be configured or rated for use with pressurized fluids including being rated for use at 10 MPa, 25 MPa, 50 MPa, 70 MPa, 90 MPa, 110 MPa, 130 MPa, 150 MPa, or the like. In one preferred embodiment, a fitting **410** comprising a stem **520** and ferrule **540** as described herein can be rated for use with pressurized hydrogen at 70 MPa nominal working pressure. In another preferred embodiment, a fitting **510** comprising a stem **520** and ferrule **540** as described herein can be rated for use with compressed natural gas (CNG) at 25 MPa nominal working pressure. Although various embodiments discussed herein can be configured for use with fuel fluids such as hydrogen or CNG, further embodiments can be configured for use with any suitable fluid at various suitable pressures. Additionally, some embodiments can be configured for use with cryogenic fluids, room-temperature fluids, or heated fluids.

Turning to FIG. **6**, a tank filling system **600** of one embodiment **600**A is illustrated that comprises a control device **610** that drives a valve assembly **620** to direct fluid from a fluid source **630** to filling couplers **640** via fluid lines **650**. The filling couplers **640** are removably coupled to fittings **410** on ends **415** of a tank **100**. More specifically, a first filling coupler **640**A is removably coupled to a first fitting **410**A at a first end **415**A of the tank **100**, and a second filling coupler **640**B is removably coupled to a second fitting **410**B at a second end **415**B of the tank. The control device can be operably connected to the filling couplers **640** as described in more detail below.

The filling couplers **640** can be removably coupled to the fittings **410** in various suitable ways. For example, referring to the example fittings **410** of FIG. **5**, filling couplers **640** can couple with the threads **525** on the head **524** of the stem **520**, which can provide a fluid-tight seal between the filling coupler **640** and the fittings **410**. Additionally, in various embodiments, the filling couplers **640** can comprise one or more sensors, which can include a temperature sensor, pressure sensor, velocity sensor, and the like. When a filling coupler **640** is coupled with a fitting **410**, such sensors can be disposed within the body of the filling coupler **640**, and can extend into and be disposed within the fittings **410** (e.g., within the bore **521**) or within a portion of the tank **100** (e.g., the cavity **505**).

The control device can comprise any suitable computing system or computing device, which can receive data from one or more sensors associated with the fitting couplers **640**, tank **100** or the like, via wired and/or wireless communication. The control device **610** can control the one or move valves **620** to control flow of fluid from the fluid source **630** to the ends **415** of the tank **100** via the fluid lines **650**. Although one example configuration of valves **620** is illustrated in FIG. **6**, it should be clear that any suitable configuration of one or more valves, or the like, is within the scope and spirit of the present disclosure, and the example configuration of FIG. **6** should not be construed to be limiting. For example, the illustration of FIG. **6** should not be construed to exclude configuration having valves collocated at the fluid source **630**, fitting couplers **640**, or the like.

Pressurized gaseous fuel tanks can experience heating when filled due to heat of compression and, for some gasses, to the Joule-Thompson effect. For safety, some compressed fuel filling stations control the filling rate to avoid dangerously high temperatures. In addition, the high temperatures can be undesirable because they can result in low density at a given pressure, thus requiring overpressure to reach the target density (state of charge near 100%) or under-filled tanks.

Such heat generation can therefore result in undesirably long filling times that take longer than filling gasoline or diesel fuel tanks and/or under-filled tanks. To mitigate these issues associated with gaseous fuel tanks, many stations have the option of gas pre-cooling. With gas pre-cooling, the gas is cooled to a low temperature (e.g., as low −40° C.) before the gas enters the tank. This has the effect of lowering the maximum temperature that the gas reaches due to heat of compression, since the initial temperature is lower.

Gas pre-cooling can add significant additional complexity to the construction of fueling stations, which can undesirably increase capital cost and operational cost for the fueling station. This increased cost may be transferred to the customer in the form of higher gas prices. In addition, pre-cooling components can have poor reliability in some examples, resulting in significant station downtime and additional cost due to maintenance and replacement parts.

Novel conformable tanks discussed herein and in related applications (e.g., U.S. Ser. No. 13/887,201; U.S. Ser. No. 14/172,831; U.S. Ser. No. 14/624,370; U.S. Ser. No. 15/183,614; and U.S. Ser. No. 15/368,182, which are hereby incorporated herein by reference) can be advantageous over conventional monolithic compressed gas tanks because the conformable shapes can have more surface area per unit volume of storage. Such increased surface area can allow for more rapid heat dissipation, which can increase fast-fill performance. In addition, such conformable tanks can have a smaller cross-sectional area, which can result in higher flow velocity during filling and hence better convective heat transfer from the gas to the tank wall (i.e., higher Nusselt number).

During filling or fast-fill, such novel pressure vessels can reach a lower average temperature than conventional pressure vessels. This can be because such novel pressure vessels have a higher ratio of surface area to volume, and because the gas can have a higher average speed due to the smaller tank diameter, resulting in greater convective heat transfer. This can result in a reduced need for gas precooling. Conformable pressure vessels can thus be filled with fluid that is precooled to a higher temperature or not precooled at all, while still achieving the filling speeds that are normally associated with pre-cooled gas.

However, in some embodiments, less mixing can occur during the filling of various example tanks **100** or pressure vessels due to their elongated shape, meaning that the difference between maximum and minimum temperature at the end of a filling can be much more extreme than for other configurations of pressure vessels. In particular, the gas temperature near the ends **415** can remain close to the temperature of the inflowing gas, since the flow speed at the ends **415** can result in good heat transfer to the walls. The chambers of the tank **100** that are far from the ends **415**, on the other hand, can heat up considerably because there is little flow in the far region of the tank **100** and hence have poor convective heat transfer.

Such a temperature rise at one end **415** of the tank **100** in such embodiments can be mitigated by filling from alternating ends **415**A, **415**B of the tank **100**. For example, at the start of fill, the tank **100** can be filled from the first end **415**A, and the temperature at the second end **415**B can rise. When the temperature at the second end **415**B reaches a defined high value, the inlet to the first end **415**A can be closed, and the inlet to the second end **415**B can be opened. Thus, in various embodiments, the end **415** that is hottest can be given a high flow velocity and can dump heat to the walls of the tank **100**. This pattern can be repeated until the tank **100** is filled. The frequency of flow switching can be chosen so that the fluid temperature of the tank **100** stays below a target maximum temperature.

Turning to FIG. **7**, a block diagram of method **700** of filling a tank **100** with fluid in accordance with one embodiment is illustrated. The method **700** begins at **705**, where a first fitting coupler **640**A is coupled with a first fitting **410**A at a first end **415**A of a tank **100** (e.g., see FIG. **6**). At **710**, a second fitting coupler **640**B is coupled with a second fitting **410**B at a second end **415**B of the tank **100**.

The method **700** continues to **715**, where filling of the tank **100** with fluid at the first end **415**A is initiated. For example, referring to the example tank filling system **600** of FIG. **6**, the tank **100** can be filled with fluid from the fluid source **630** by the control device **610** actuating one or more of the valves **620** such that fluid from the fluid source **630** travels via a fluid line **650** to the first fitting coupler **640**A, where the fluid enters the first fitting **410**A and enters the first end **415**A of the tank **100**. In some examples, filling can be initiated by a user actuating a button associated with the tank filling system **600** and the control device **610** can confirm suitable coupling between the fitting couplers **640** and fittings **410** before initiating filling at the first end **415**A.

Returning to the method **700**, at **720** a determination is made whether filling is complete. For example, in various embodiments a fill status of the tank **100** can be determined based at least in part on data from one or more sensors associated with the tank **100** and/or fitting couplers **640**. In one example, one or both of the fitting couplers **640** can include a pressure sensor that determines a pressure of fluid within the tank **100**, which can be used to determine a fill state of the tank **100**. In other words, one or more pressure sensors can be used to determine whether the tank **100** is full or at a filling threshold based at least in part on a determined pressure of the tank **100**.

If at **720** filling is not complete, then the method **700** continues to **725**, where a determination is made whether a temperature of the first end **415**A of the tank **100** has reached a threshold. For example, in various embodiments, the first fitting coupler **640**A can comprise a temperature sensor that can sense a temperature at the first end **415**A of the tank **100**. Temperature thresholds can be any suitable temperature threshold, including a maximum temperature threshold of 85° C. However, in further embodiments, such a maximum threshold can include 60° C., 70° C., 80° C., 90° C., 100° C., and the like.

If at **725** a temperature at the first end **415**A has not reached the temperature threshold, then the method **700** cycles back to **715**, where filling of the tank **100** at the first end **415**A continues. However, if a temperature at the first end **415**A has reached the temperature threshold, then at **730**, filling of the tank **100** at the first end **415**A is stopped, and at **735**, filling of the tank **100** at the second end is initiated. For example, the control device **610** can receive temperature readings from one or more temperature sensors associated with the first fitting coupler **640**A and determine whether the temperature at the first end **415**A has reached the temperature threshold. The control device **610** can control the one or more valves **620** to maintain filling at the first end **415**A or to stop filling at the first end **415**A and begin filling at the second end **415**B.

Returning to the method **700**, at **740**, a determination is made whether filling is complete, and if not, the method **700** continues to **745** where a determination is made whether a temperature at the second end **415**B has reached a temperature threshold. If not, the method **700** cycles back to **735**, where filling at the second end **415**B is maintained. However, where it is determined that a temperature at the second end **415**B has reached a temperature threshold, then the method **700** continues to **750**, where filling at the second end is stopped, and then at **715**, filling of the tank **100** at the first end is initiated.

As shown in the example method of FIG. **7**, filling can alternate between the first and second ends **415**A, **415**B until it is determined that filling is complete at **720** or **740**. For example, where the control device **610** obtains data from one or more sensors associated with the tank **100**, filling couplers **640**, or the like, that indicates that the tank **100** is full or at a filling threshold, then filling at the first and/or second ends **415**A, **415**B can be terminated to stop filling at **799**. The first and second filling couplers **640**A, **640**B can then be removed from the first and second fittings **410**A, **410**B at the first and second ends **415**A, **415**B of the tank **100**.

In various examples, any of the steps or operations of the method **700** of FIG. **7** can be performed automatically and without human intervention. For example, the control device **610** can, beginning at **715**, initiate filling of the tank **100**; determine whether filling of the tank is complete, switch filling between ends **415**; maintain filling at an end **415**; determine whether a temperature at the ends **415** has reached or exceeded a temperature threshold; and stop a filling session at **799**. In further examples, coupling and/or de-coupling of the filling couplers **640**A, **640**B can also be automated, including via an automated docking station, robotic arm(s), and the like.

A simulation study was performed comparing one example of a tank **100**B as shown in FIG. **8** to a conventional tank having the parameters illustrated in FIG. **9***a*. A 3D simulation for the example tank **100**B (5 kg having one hundred and twelve tubing portion chambers **130**) was performed for the four cases illustrated in FIG. **9***b*, and a 1D simulation was performed for the conventional tank for the same four cases illustrated in FIG. **9***b*.

Each of the test cases included:

20° C. ambient temperature, 30° C. "hot soak"

0.5 MPa initial pressure

21.8 MPa/min., as per SAE J2601

H70-T40 (−33° C. pre-cool)

Fill time of 3.1 minutes to 67.9 MPa

NOTE: In some embodiments, no standard exists for 0° C. pre-cool or no pre-cool, but the 70-T20 specification allows for −17.5° C. pre-cool. This can require 6.7 MPa/min. for a 9.9 minute fill.

Plots of various results are illustrated in FIGS. **10**-**13**.

The results can illustrate the following for various embodiments of the novel tank **100** compared to conventional tanks:

Increased surface area and flow velocity of novel tanks **100** can allow for better heat transfer in various embodiments. Accordingly, pre-cool can be unnecessary in such embodiments of tanks **100**. In some embodiments, it can be desirable for materials to be designed for working temperature of 120° C. However, if 120° C. working temperature is not possible, filling from alternating ends can keep maximum temperature well below 85° C., in accordance with some embodiments. More specifically, the 3D results show maximum temperatures at the last chamber of 120° C. and 116° C., respectively. These temperatures are higher than a limit of 85° C., but that limit applies only to the average temperature of the pressure vessel as a whole.

Additionally, the following was observed during these tests:

Flow rate is <3 g/s for 10-chamber tanks. For a 4.5 kg tank, required flow rate is ~30 g/s for a 3-minute fill. Highest temperature is at the far end of the tank, where gas is the most stagnant and, therefore, has the lowest heat transfer coefficient for transferring heat to the walls. For some tank sizes, peak temperature goes down as number of chambers goes up—this can be because the flow rate goes up, so more heat is transferred to walls as gas is flowing. Initial gas in the tanks can be the gas that hits peak temperatures, since this gas is not pre-cooled and has a low thermal mass due to low initial density. Tank pressure can be nearly uniform throughout tank during fill—this surprising result indicates that the flow resistance caused by the bends can be negligible.

In some examples, a challenge with tanks **100** is how to estimate the state of charge (SOC) of a tank **100** during filling, if the difference in temperature from between the first and second ends **415**A, **415**B is extreme. The average density must be determined in some examples in order to know the SOC, and to estimate the average density, two thermodynamic state variables can be required: the average pressure and the average temperature. The simulations show very little deviation in pressure along the length of the tank **100**, so the average temperature is the only unknown in various examples.

In some embodiments it is possible to estimate density using temperature at the non-filling end. Density can have a weak dependence on temperature in the relevant range of temperatures. Therefore, the temperature at the non-filling end of the tank can be used as a replacement for the average temperature when estimating the average density. For example, a filling simulation with no precool ends when P_{avg}=85 MPa and T_{avg}=83° C., yielding an average final density of ρ_{avg}=39.6 g/L. If instead the temperature of the last chamber T_{last}=116° C. were used, it would result in an estimated final density of ρ_{avg}=37.2 g/L, which is only 6% off from the actual value. Note too that this can yield a conservative estimate, thereby ensuring that the tank **100** will not be over-pressurized.

Some embodiments can estimate density using flux of gas during filling. Before filling, the initial density, $\rho_{initial}$, can be estimated accurately in some examples since there may be minimal temperature variations within the tank **100**. Given this value and the tank volume, V, the density can be estimated during filling by integrating the mass flux into the tank, $\dot{m}(t)$. In hydrogen filling stations, for example, it can be necessary in some embodiments to have an accurate estimate of the mass flux in order to charge the customer for fuel, so this information may already be available. The average density can then be given by the equation

$$\rho_{avg}(t) = \rho_{initial} + \frac{\int_0^t \dot{m}(\tau)d\tau}{V}.$$

In another example, a fueling and defueling simulation of a 50-chamber, 10 kg tank **100** was conducted to measure state of charge (SOC) of the tank. In various examples, it can be desirable to measure the instantaneous (SOC) of a tank **100** during fueling and defueling of the tank **100** to within a certain accuracy, which entails measuring the average density to within a certain accuracy. In order to estimate the average density, and hence the SOC, the average pressure and average temperature in the tank **100** can be determined. In various examples, pressure deviations in the tank **100** can be considered minimal; therefore, it can be desirable to determine the average temperature.

In some examples, it can be challenging to determine the average temperature at the end of fueling for various reasons including temperature being least homogenous at the end of fueling. Additionally, pressure can be highest at the end of fueling, so incorrect temperature measurements can lead to a large absolute error in density measurement.

In some embodiments, sensors (e.g., thermocouples or the like) can be disposed at the first and second ends **415**A, **415**B of a tank **100** (e.g., associated with fitting couplers **640**). Accordingly, in various examples, such sensors we can be used to determine the SOC in the first and last (i.e., 50^{th}) chamber:

$$SOC_1=\rho(p,T_1)/\rho(70\text{ MPa},15°\text{ C.})$$

$$SOC_{50}=\rho(p,T_{50})/\rho(70\text{ MPa},15°\text{ C.})$$

One way to determine the average SOC of the tank **100** includes averaging readings from sensors at the first and second ends **415**A, **415**B of a tank **100**,

$$SOC_{tank}=(SOC_1+SOC_{50})/2$$

However, in some examples, such a calculation may not produce an estimate that is accurate enough to meet a desired accuracy threshold. Since SOC_{tank} can be closer in value to SOC_{50} than to SOC_1, an alternative method of determining SOC_{tank} can include taking a weighted average of the readings from sensors at the first and second ends **415**A, **415**B of a tank **100**, so that SOC_{50} is weighted higher than SOC_1,

$$SOC_{tank}=(\alpha \cdot SOC_1+SOC_{50})/(1+\alpha).$$

In various examples, $\alpha<1$ can produce a desirable estimate of the SOC_{tank}, since $\alpha<1$ can result in a formula that weights the SOC of the chambers **130** at the terminal end **415**B of the tank **100** more than the chambers **130** at the beginning end **415**A.

During filling of an elongated and folded tank **100** with fluid, the fluid within the tank can exceed a maximum desired temperature limit locally, even if the average fluid temperature within the tank **100** stays below such a desired maximum temperature limit. This can be due to the fact that there is limited mixing in some embodiments of such tanks **100**, where the fluid at a non-filling second end **415**B of the tank **100** heats up due to having a low flow velocity (and hence low heat transfer) but is not able to mix with cool fluid near an inlet end **415**A.

Various suitable temperature limits can be accommodated in accordance with embodiments discussed herein. For example, vessel regulatory standards (such as UN GTR 13, SAE J2579, SAE J2601) are written for a maximum gas temperature of 85° C. due to a maximum tank component temperature of 85° C. However, in further embodiments, a maximum gas temperature can include 60° C., 70° C., 80° C., 90° C., 100° C., and the like.

In some embodiments, filling the tank **100** from alternating ends as discussed herein can result in lower maximum (as well as average) temperatures, due to various effects. For example, when the filling end is switched, the hot stagnant fluid at the non-filling end **415** of the tank **100** can be given a high flow velocity by filling, allowing the fluid to dump heat to the walls of the tank **100**. In another example, when the filling end is switched, the cold incoming fluid can mix with the hot fluid at the end that was formerly the outlet, helping to decrease the maximum temperature in that location.

In further embodiments, a Venturi nozzle (also known as an eductor or an ejector) can be used to circulate fluid flow during the filling process, which can result in lower maximum (as well as average) temperatures of the fluid and/or tank **100** during filling. For example, FIG. **14** is a schematic showing a Venturi assembly **1400** circulating fluid flow during the filling of an example 6-chamber tank **100**. FIG. **15** is a close up schematic showing the Venturi assembly **1400** circulating the flow during the filling of the tank **100**.

The Venturi assembly **1400** is shown comprising a Venturi nozzle **1405** that introduces a flow of fluid to a Venturi chamber **1410**. The mixing chamber of the Venturi **1410** is connected to an inlet **1415** that communicates with a first end **415**A of the tank **100** and introduces fluid into the interior cavity **505** of the tank **100**. An outlet **1420** is shown coupled at a second end **415**B of the tank **100**, with the outlet **1420** coupled with the Venturi chamber **1410** that introduces a flow of fluid into the Venturi chamber **1410** that originates from fluid leaving the second end **415**B of the tank **100**.

As shown in FIG. **15**, fluid can enter the Venturi assembly **1400** via the Venturi nozzle **1405** at an inlet pressure p_{fill} before accelerating through the nozzle **1405** with diameter D_{noz}, where the pressure drops to p_{noz} due to the increased speed of the flow. The low pressure draws in the fluid from the outlet **1420** of the tank **100**, which enters the Venturi chamber **1410** at a pressure p_{out}. The two fluid streams from the nozzle **1405** and outlet **1420** can mix in the Venturi chamber **1410** and then exit the Venturi chamber **1410** via the inlet **1415** to enter the first end of the tank **100**, at a pressure p_{in}. In some embodiments, the Venturi assembly **1400** and tank **100** can be configured to operate with a maximum mass flow rate $\dot{m}_{fill}$ of 60 g/s. In further embodiments, it can be desirable for a tank **100** and Venturi assembly **1400** be configured for, and to be filled at, a maximum pressure ramp rate of less than or equal to 28.5 MPa/min.

Use of a Venturi assembly **1400** can decrease the maximum temperature during filling in various ways. In one example, the flow at the second end **415**B of the tank **100**, rather than being stagnant, can have a mass flow rate $\dot{m}_{out}$, which can enable better heat transfer from the hot fluid to the walls of the tank **100**. In another example, there can be less temperature variation overall throughout the tank **100**, since the hot fluid at the second end **415**B of the tank **100** can be removed from the tank **100** via $\dot{m}_{out}$, and mixed with the cold filling gas, $\dot{m}_{fill}$. Then, the hot gas at the second end **415**B of the tank **100** can be replaced with cooler gas that is flowing from the inlet of the tank **1415**.

In some embodiments, it can be desirable for the pumping pressure of the nozzle **1405** to be strong enough to generate a significant circulating mass flow, $\dot{m}_{out}$. In various examples, the amount of circulating flow, $\dot{m}_{out}$, can be determined by a balance between the dynamic pressure drop in the Venturi valve and the pressure drop through the tank **100** and connecting tubing **650**. In further examples, for a fixed Venturi nozzle geometry, the circulating mass flow rate, $\dot{m}_{out}$, can be approximately proportional to the filling mass flow rate, $\dot{m}_{fill}$, and not dependent on the instantaneous pressure, density, or temperature. In other words, $\phi=\dot{m}_{out}/\dot{m}_{fill}$ is only a function of geometry and flow resistance (which is itself a function of geometry) in various examples.

In some embodiments, a smaller Venturi nozzle diameter D_{noz} can lead to a greater dynamic pressure drop and hence more circulation. However, the nozzle diameter D_{noz} can be limited by choking concerns. If the nozzle diameter D_{noz} is too small in some embodiments, the nozzle **1405** will choke, restricting flow into the tank **100**. This can cause the tank **100** to fill slower at low pressures and to speed up in filling rate once the tank **100** fills enough to eliminate the choking condition. Then, the tank **100** may not reach a full state of charge at the end of filling. In some examples, it can be desirable to configure a Venturi assembly **1400** having a nozzle diameter $D_{noz}>16.5$ mm. In further examples, it can be desirable to configure a Venturi assembly **1400** having a minimum of 6 mm inner diameter for the Venturi nozzle **1405**. In still further examples, it can be desirable to configure a Venturi assembly **1400** having a minimum of 2 mm, 3 mm, 4 mm, or 5 mm inner diameter for the Venturi nozzle **1405**, or other suitable minimum diameter.

Additionally, it can be desirable to use a Venturi nozzle **1405** with a varying diameter, so that the nozzle diameter D_{noz} can be decreased when choking is not a concern. For example, the nozzle diameter D_{noz} can be decreased once the tank **100** reaches a high enough absolute pressure and/or at high ambient temperature when the filling rate is slower.

In some embodiments, the ratio ϕ can be increased by increasing the inner diameter of corrugations **111** of a tank **100** (see e.g., FIGS. **1**, **2***a* and **3**). In some examples, improved circulation can be obtained through increasing corrugation inner diameter while keeping the ratio of corrugation inner diameter to outer diameter constant, and while keeping the ratio of corrugation outer diameter to chamber outer diameter constant. In further examples, improved circulation can also be obtained through increased corrugation inner diameter while keeping corrugation outer diameter constant.

In some embodiments, it can be desirable for tubing **650** that connects the second end **415**B of the tank **100** to the Venturi chamber **1410** to be as short and as wide as possible. In some examples, this can limit potential tank designs by requiring the two ends **415** of the tank **100** to be positioned near each other.

In further examples, the Venturi assembly **1400** can be placed directly at the first end **415**A of the tank **100** in order to minimize losses and maximize circulation. In some examples, tubing **650** should only be used to connect the second end **415**B of the tank **100** to the Venturi suction port.

FIG. **16** is a schematic showing a tank **100** having i+3 chambers **130**. In various embodiments, increasing or decreasing the number of chambers **130** in a tank **100** can change fluid circulation through a tank **100**. For example, decreasing the number of chambers **130** can also increase circulation through decreased flow resistance. This effect can be more prominent for tanks **100** with smaller diameters of corrugations **111**. In some examples, additional chambers **130** can add a negligible amount of flow resistance for some tank geometries. While various embodiments can have any suitable plurality of chambers **130**, in some embodiments it can be desirable to configure a tank **100** for a capacity of 7-10 kg regardless of the number of chambers **130**.

In some embodiments, it can be desirable to split a tank into multiple units. For example, splitting a tank into multiple units can increase the amount of gas circulation, since the diameter of the Venturi nozzle **1405** can be decreased due to less mass flow per tank, thrill, being required.

In various embodiments, it can be desirable to make the Venturi nozzle **1405** as small as possible so that Venturi nozzle **1405** provides as much suction pressure as possible without choking the flow. In further embodiments, it can be desirable to reduce the hydraulic resistance of the tank **100** (e.g., the tubing portions **130**, connector portions **110**, and the like) as much as possible. For example, in some embodiments reducing the hydraulic resistance of the tank **100** can be done by increasing the diameter of corrugations **105**, making the connector portions **110** as short and/or a wide as possible, and the like. In some examples, a purpose of one or both of such elements can be to enable as high a ratio of $\dot{m}_{out}/\dot{m}_{fill}$, as possible.

Also, while various embodiments discussed herein relate to introducing fluid into a tank **100**, various embodiments can be employed similarly during defueling, which can limit the temperature variations in the tank **100** during defueling and/or can reduce the temperature drop in the tank **100** during defueling. Additionally, while some examples herein may be discussed in relation to gas, in further embodiments any suitable fluid can be used to fill a tank **100** or be held within a tank **100**, including one or both of liquids and gases. Also, while hydrogen gas storage tanks are discussed in some embodiments, any other suitable fluid fuel can fill and be held within a tank **100** in further embodiments, including natural gas, oxygen, methane, propane, acetylene, or the like. Additionally, some embodiments can include use of any suitable non-fuel gasses.

In various embodiments, the Venturi **1400** can be part of a passive filling system that does not require control devices, temperature sensors, and the like. In other words, in some examples, the fluid flow through the Venturi **1400** solely drives recirculation. However, in further embodiments, the Venturi **1400** can include active control. For example one embodiment can include Venturi recirculation with a variable diameter of the Venturi nozzle **1405**. Another embodiment can include Venturi recirculation combined with end switching.

Turning to FIG. **17**, a tank filling system **600** of another embodiment **600**B is illustrated that comprises a control device **610** that drives a valve assembly **620** associated with one or more Venturi **1400** to direct fluid from a fluid source **630** to filling couplers **640** via fluid lines **650**. The filling couplers **640** can be removably coupled to fittings **410** on ends **415** of a tank **100**. More specifically, a first filling coupler **640**A is removably coupled to a first fitting **410**A at a first end **415**A of the tank **100**, and a second filling coupler **640**B is removably coupled to a second fitting **410**B at a second end **415**B of the tank. The control device **610** can be operably connected to the filling couplers **640** as described herein.

The control device can comprise any suitable computing system or computing device, which can receive data from one or more sensors associated with the fitting couplers **640**, tank **100**, or the like, via wired and/or wireless communication. The control device **610** can control the one or move valves **620** to control flow of fluid from the fluid source **630** to the ends **415** of the tank **100** via the fluid lines **650** and control the flow of fluid from the ends **415** of the tank **100** to the one or more Venturi assembly **1400**. Although one example configuration of valves **620** and one or more Venturi assembly **1400** is illustrated in FIG. **17**, it should be clear that any suitable configuration of one or more valves, one or more Venturi assembly, or the like, is within the scope and spirit of the present disclosure, and the example configuration of FIG. **17** should not be construed to be limiting.

For example, the illustration of FIG. **17** should not be construed to exclude a configuration of a filling system **600** having valves collocated at the fluid source **630**, fitting couplers **640**, or the like. In another example, a filling system **600** can include the configuration as shown in FIGS. **14** and **15** where a single Venturi assembly **1400** introduces fluid to the first end **415**A of the tank **100** with the second end **415**B of the tank **100** providing an outlet **1420** that feeds into the Venturi chamber **1405**.

In some embodiments, the filling system **600** can be non-alternating. In other words, the filling system **600** may not switch the filling end **415** between the first and second ends **415**A, **415**B. Accordingly, in some embodiments, the first end **415**A can remain the inlet **1415** and the second end can remain the outlet **1420**. However, in further embodiments, the inlet **1415** can switch between the first and second ends **415**A, **415**B with the outlet **1420** similarly switching between the first and second ends **415**A, **415**B. For example, the valves **620** can be configured to switch the inlet **1415** and outlet **1420**.

In another example, the filling system can comprise a first and second Venturi assembly **1400** that are respectively associated with first and second ends **415**A, **415**B with the first Venturi assembly **1400** having the first end **415**A as the inlet **1415** and the second end **415**B as the outlet **1420**. The second Venturi assembly **1400** can have the first end **415**A as the outlet **1420** and the second end **415**B as the inlet **1415**. In such examples, the valve(s) **620** can switch between the first and second Venturi to switch filling from the first and second ends **415**A, **415**B.

Such switching of filling between the first and second ends **415**A, **415**B having one or more Venturi can be achieved as discussed herein and as illustrated in FIG. **7**, with the switching between the inlet filling end **1415** also including switching of the outlet end **1420**.

The described embodiments are susceptible to various modifications and alternative forms, and specific examples thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the described embodiments are not to be limited to the particular forms or methods disclosed, but to the contrary, the present disclosure is to cover all modifications, equivalents, and alternatives.

It should be noted that the figures are not drawn to scale and that elements of similar structures or functions are generally represented by like reference numerals for illustrative purposes throughout the figures. It also should be noted that the figures are only intended to facilitate the description of the preferred embodiments. The figures do not illustrate every aspect of the described embodiments and do not limit the scope of the present disclosure.

What is claimed is:

1. A method of filling an elongated folded tank having a first and second end, the method comprising:

coupling a filling coupler with a Venturi filling system that is coupled with an elongated folded tank having a first end and a second end, the Venturi filling system comprising:

a Venturi assembly having a Venturi nozzle that introduces a first flow of a fluid from a fluid source to a Venturi mixing chamber of the Venturi assembly, the Venturi mixing chamber communicating with the first end of the elongated folded tank to introduce the fluid to the first end and into an interior cavity of the tank, the Venturi assembly further including a suction inlet communicating with the second end and coupled with the Venturi mixing chamber such that a second flow of fluid that originates from the second end of the tank flows into the Venturi mixing chamber and mixes with the first flow of the fluid within the Venturi mixing chamber, wherein the Venturi nozzle of the Venturi assembly is configured to have a varying diameter during filling so that a nozzle diameter D_{noz} is increased and decreased during filling;

wherein the elongated folded tank extends between the first end and second end and the elongated folded tank includes:

a plurality of elongated rigid tubing portions having a first diameter,

a plurality of connector portions having a second diameter that is smaller than the first diameter and having flexible corrugations and a rigid cuff, and

taper portions disposed between and coupling successive tubing portions and connector portions;

introducing the first flow of the fluid into the first end of the tank via the filling coupler and the Venturi assembly to generate the second flow of fluid that originates from the second end of the tank that flows into the Venturi mixing chamber via the suction inlet and mixes with the first flow of the fluid within the Venturi mixing chamber;

determining that tank filling is complete;

stopping any fluid flow to the tank; and

de-coupling the filling coupler from the Venturi filling system.

2. The method of claim **1**, wherein the determining that tank filling is complete is performed by a computing device automatically without human interaction.

3. The method of claim **1**, wherein the first and second flows of the fluid comprise hydrogen.

4. The method of claim **1**, wherein the Venturi assembly and tank operate with a maximum mass flow rate Thrill of 60 g/s and a maximum pressure ramp rate of less than or equal to 28.5 MPa/min.

5. The method of claim **1**, wherein Venturi assembly is disposed directly at the first end of the tank such that a first length of fluidic coupling between the Venturi assembly and first end of the tank is substantially shorter than the length of a second length of fluidic coupling between the Venturi assembly and second end of the tank.

6. A system comprising:

an elongated folded tank that extends between a first and second end of the tank, the elongated folded tank including:

a plurality of elongated rigid tubing portions having a first diameter,

a plurality of connector portions having a second diameter that is smaller than the first diameter and having flexible corrugations, and

taper portions disposed between and coupling successive tubing portions and connector portions; and

a Venturi filling system coupled to the elongated folded tank, the Venturi filling system comprising:

a first filling coupler coupled to a first set of fittings disposed at a first tank end;

a second filling coupler coupled to a second set of fittings disposed at a second tank end; and

a Venturi assembly that includes:

a Venturi mixing chamber, the Venturi mixing chamber communicating with the first filling coupler to introduce fluid to the first tank end and into an interior cavity of the tank;

a Venturi nozzle configured to introduce a first flow of fluid from a fluid source to the Venturi mixing chamber of the Venturi assembly, wherein the Venturi nozzle of the Venturi assembly is configured to have a varying diameter during filling so that a nozzle diameter D_{noz} is increased and decreased during filling; and

an suction inlet communicating with the second filling coupler and coupled with the Venturi mixing chamber such that where a second flow of fluid originates from the second end of the tank, the second flow of fluid flows into the Venturi mixing chamber and mixes with the first flow of the fluid within the Venturi mixing chamber.

7. The system of claim **6**, wherein the first flow of the fluid comprises hydrogen.

8. The system of claim **6**, wherein the Venturi assembly and tank operate with a maximum mass flow rate $\dot{m}_{fill}$ of 60 g/s.

9. The system of claim **6**, wherein the Venturi assembly and tank operate with a maximum pressure ramp rate of less than or equal to 28.5 MPa/min.

10. The system of claim **6**, wherein Venturi assembly is disposed at the first end of the tank with a first length of fluidic coupling between the Venturi assembly and first end of the tank being substantially shorter than the length of a second length of fluidic coupling between the Venturi assembly and second end of the tank.

11. A Venturi filling system comprising:

a first filling coupler configured to be coupled to a first set of fittings disposed at a first tank end of a tank;

a second filling coupler configured to be coupled to a second set of fittings disposed at a second tank end of the tank; and

a Venturi assembly that includes:

a Venturi mixing chamber, the Venturi mixing chamber communicating with the first filling coupler;

a Venturi nozzle configured to introduce a first flow of fluid from a fluid source to the Venturi mixing chamber of the Venturi assembly; and

a suction inlet communicating with the second filling coupler and coupled with the Venturi mixing chamber and configured to receive a second flow of fluid originates from the second filling coupler such that the second flow of fluid flows into the Venturi mixing chamber and mixes with the first flow of the fluid within the Venturi mixing chamber,

wherein the Venturi nozzle of the Venturi assembly is configured to have a varying diameter during filling so that a nozzle diameter D_{noz} is increased and decreased during filling of a tank that the Venturi filling system is coupled to.

12. The Venturi filling system of claim **11**, wherein the Venturi assembly operates with a maximum mass flow rate Thrill of 60 g/s.

13. The Venturi filling system of claim **11**, wherein the Venturi assembly operates with a maximum pressure ramp rate of less than or equal to 28.5 MPa/min.

14. The Venturi filling system of claim **11**, wherein the tank includes:

a plurality of elongated rigid tubing portions having a first diameter,

a plurality of connector portions having a second diameter that is smaller than the first diameter and having flexible corrugations and a rigid cuff, and

taper portions disposed between and coupling successive tubing portions and connector portions.

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